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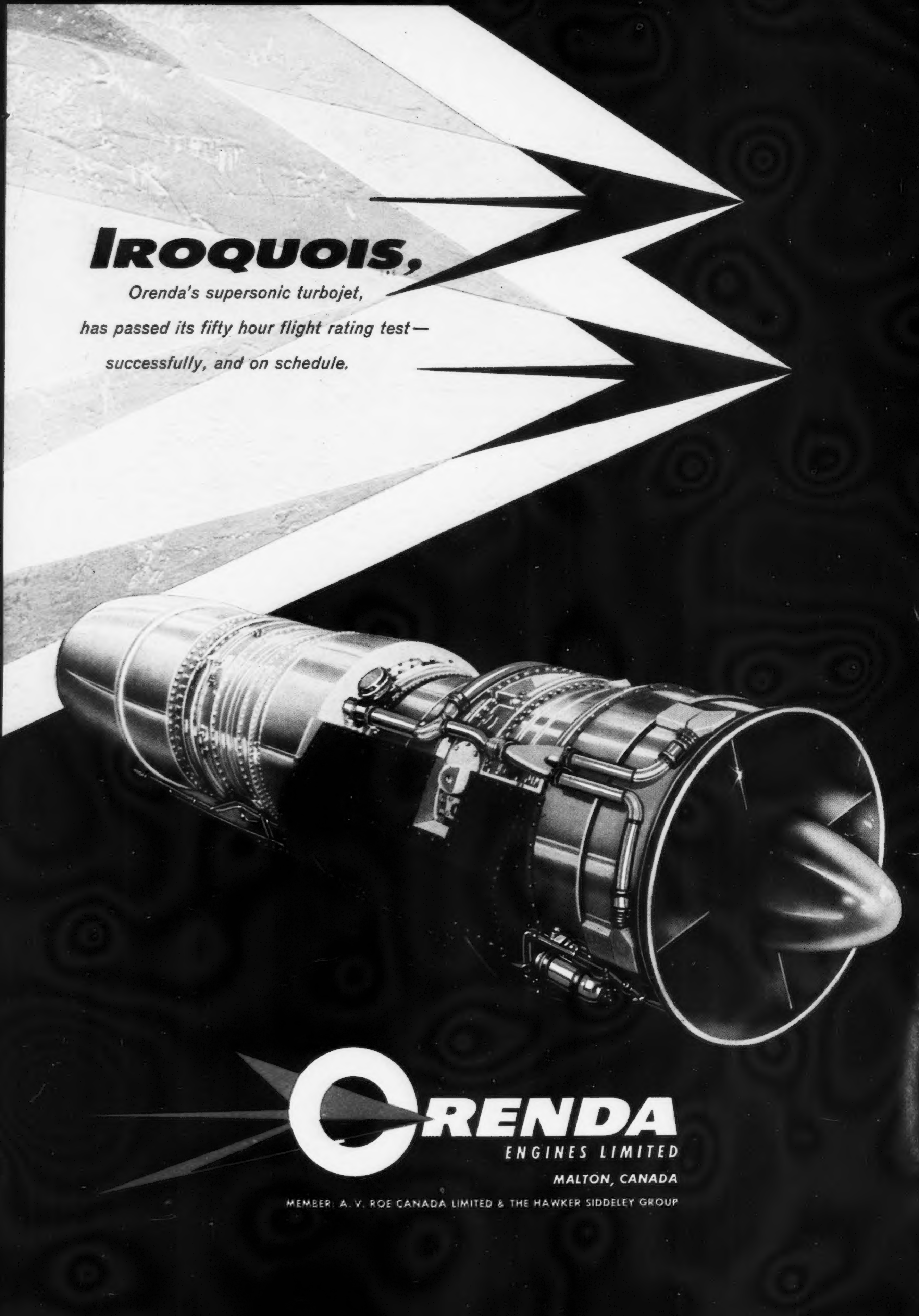
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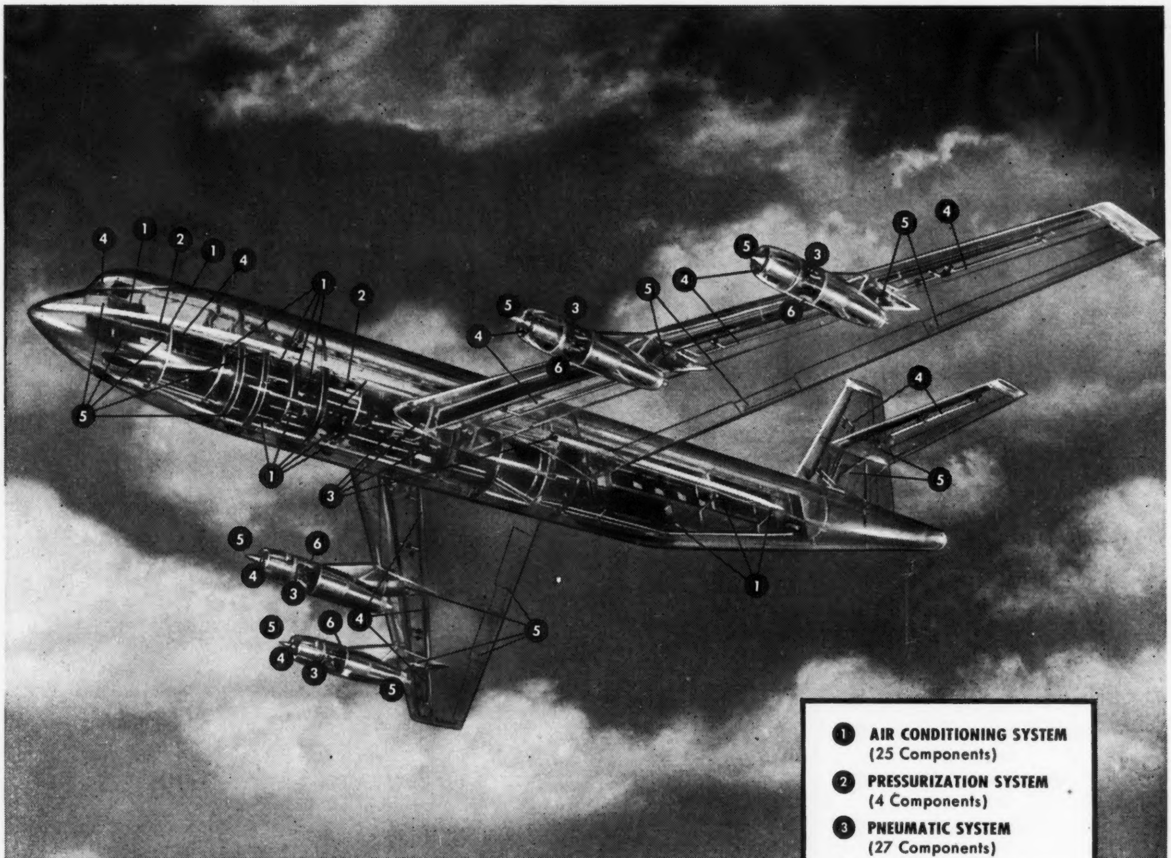

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N.A.E. REHEAT SYSTEM

National Defence Photo

The Meteor IV (Derwent VIII) incorporating an experimental reheat system developed by the N.A.E. (See page 276).

EDITORIAL

SECURITY

In our competitive society anyone making an advance in his particular art has an advantage over his competitors, commercial or military, and it is only natural that he should develop and exploit it in secrecy, so long as the advantage can be maintained. But such secret development is handicapped by the fact that relatively few minds can be brought to bear on the associated problems. Recognizing this, a braver age than ours devised the patent system to enable new and useful discoveries to be laid open to public development, while giving the inventors certain rights and protection. The patent system, with all its faults, works tolerably well in commerce, where it is subject to legal processes, but in war it can guarantee no rights or protection; national defence must rely on secrecy alone and many of the most advanced areas of knowledge are unhappily retarded by its shadow.

The Institute is dedicated to advance the art, science and engineering relating to aeronautics and, like all similar societies – and the patent system – it has adopted the free exchange of information as its principal instrument. Its members present the results of their thinking and experience as contributions to the common pool. They welcome open discussion in the belief that "two heads are better than one". Secrecy, particularly in advanced fields, is the very antithesis of the Institute's doctrine.

The exchange of information is our guiding tenet but, as people dealing with aeroplanes, we should know that modifications are inevitable in this imperfect world. However much we may deplore the demands of national defence, we must be practical and recognize that without them we may not survive to exchange anything. But to admit this does not mean that we must abandon our objectives or our most effective means of attaining them. We must steadfastly insist on being allowed to exchange information, within reason.

Reasonable restriction of what may be talked about is good "security" and deserves the fullest respect and support from the Institute, but unreasonable restriction is a disservice to aviation and must be regarded as our arch-enemy. In our view, those responsible for the classification of information have a double duty to the community; on the one hand they must protect military security and on the other – and this is equally important – they must release information promptly when its military value no longer justifies its being withheld from development for civil purposes.

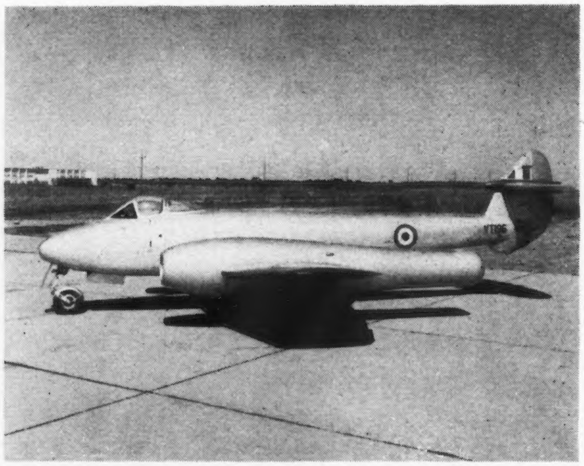
Rightly or wrongly – but probably inevitably – the classification and release of technical information is a military function and no one can blame those responsible for it for treating the release of information rather passively. Its importance to them is not immediately obvious and, in any event, appears to be secondary; furthermore it necessitates the continual review of all classified material and the exercise of fine judgment in downgrading and ultimate release. Active measures entail a good deal of technical work and, rather naturally, such technical manpower as is available is thought to be better employed in the development of new projects for military purposes than in the constant reassessment of classified information for the ultimate benefit of general aeronautical progress. In these circumstances, the release of information is likely to remain a matter of periodically "clearing out the files" or of meeting specific requests from those interested in commercial exploitation.

In the interests of technical exploitation, members of the Institute having access to classified material could render a real service by keeping their eyes open for material which seems to have lost its military significance and asking the security authorities about it. It never hurts to ask, and security clearance is often quite easy to obtain for the asking. Justifiable classification is in everybody's interest but the Institute should do its best to encourage the declassification and release of information as quickly as military considerations will allow.

REHEAT TURBOJET FLIGHT TESTING

Two views of the Meteor IV used by the National Aeronautical Establishment.

(National Defence Photos)



During 1955 a flight test programme was carried out at the Flight Research Section of the N.A.E. to evaluate the performance at altitude of a reheat system developed in the Engine Laboratory of the Establishment.

The test vehicle employed was a Gloster Meteor Mk. IV fitted with Rolls-Royce Derwent VIII engines and was made available by the British Ministry of Supply.

The reheat system is unique in that part of the reheat fuel is sprayed onto the turbine blades for cooling purposes before being burned in the reheat system. Flight tests were carried out at altitudes in excess of 40,000 ft and the results may be described as being "quite satisfactory".

AIRLINE EVALUATION OF TRANSPORT AIRCRAFT†

by A. E. Ades*

Trans-Canada Air Lines

INTRODUCTION

THE President of American Airlines, Mr. C. R. Smith, once said, "In Air Transport you do business today with yesterday's guess. Therefore, we strive to become the most scientific, deliberate, sagacious and the best guessers in the world".

In the past, the guesses by the airlines have been good and in a matter of no more than thirty years they have become an accepted part of our everyday business life on our North American Continent. However, we are today having to assume perhaps the greatest obligation in the history of air transport. At the present time the study of new replacement aircraft has resulted in the need to determine not only which manufacturer we will do business with but, far more fundamental, what type of propulsion and aircraft configuration will best do our particular job. While these studies have always been made by the airlines to a degree, never before has there been such a premium at stake on the selection of a winning combination from such an array of aircraft available from both England and the United States.

For instance, after exhaustive study, to meet our particular requirements for intercontinental operation, we find ourselves faced with a decision to purchase aircraft at a basic cost of five and one-half million dollars, weighing 300,000 pounds, accommodating 125 persons and flying at nearly 600 mph at an altitude of 35,000 feet over a 4,000 mile range.

What a tremendous gamble is placed on this guess and what a staggering responsibility to wrap up in a tube of metal and strap like a bucket of bolts to the bottom of a pilot.

In selecting the manufacturers with whom we do business, our airline has been privileged to work for many years with aircraft manufacturers in both England and the United States and we are fortunate indeed that we can swing either way without fear of injuring national pride.

For example, while it would appear that the best airframe for intercontinental jets will be available from the United States, an English engine manufacturer has an engine that at this time looks very attractive to us in that airframe. Because our association with the manufacturers in both England and the United States has been long, warm and very satisfying, this type of wedding is quite feasible and practical.

Additionally, for medium range domestic operation there are, or shortly will be, turbopropeller and turbojet aircraft available from both England and the United States with a power plant choice open to us for either combination. While this is obviously a very desirable situation from an airline operator's point of view, it does impose a very severe burden on the airline's analytical and selection activity.

For example, not only must an intermediate range turboprop vs turbojet decision be reached, with possible combinations of aircraft and power plant from either England or the United States, but we must also consider the effects of possible integration of the intercontinental jet into our transcontinental operation. We obviously cannot permit the intercontinental jet aircraft to sit overnight on the ground, as the piston powered aircraft have to do because of their inability to perform round trip Atlantic operation in twenty-four hours. Therefore, it has been necessary to produce inter-related studies, which are now being fined down to evaluate effects of integration between trans-continental and inter-continental operation, thus increasing the utilization of the big jet and adding materially to its earning capacity. This integration of aircraft materially changes the traffic distribution picture in the domestic field and, in turn, further increases the complexity of studies of the medium range aircraft.

While there are obviously innumerable problems which must be solved in the selection of aircraft, I think it might be well at this point to mention that Trans-Canada Air Lines presently serves forty communities in Canada and twenty in the United States, United Kingdom, Europe and the Caribbean area. This service requires that the aircraft selected must be capable of operating over routes which span a quarter of the globe and through weather conditions varying from sub-arctic to tropical. The geographical magnitude of this operation introduces an inter-airline competitive problem which apparently is not too well understood. On our overseas and major trans-border routes direct air competition prevails. Further, because our Canadian economy is still restricted to a very narrow corridor in close proximity to the international border, we meet very definite competition from some of the larger United States carriers who operate close to the border. In aircraft evaluation

†Paper read at the Annual General Meeting of the C.A.I. in Montreal on the 4th May, 1956.

*Assistant Director of Engineering.

then, we must always be very aware of our sister airlines' re-equipment programs.

I fully realize that adequate and detailed treatment of the numerous problems of airline aircraft evaluation is beyond the scope of this paper or of any single text for that matter. Therefore, rather than attempt to be specific in the actual problem solving area, I hope it will be helpful to try and briefly outline some of the areas of investigation and perhaps point out a few pertinent guide posts.

In general, it would appear that identification and isolation of a problem usually makes the solution reasonably simple. In any case, we have no secret formula or complex mathematical equations up our technical sleeve. Rather, we have, I believe, a very aware and experienced problem solving group of people in the airline. A great deal of the information necessary to evaluation is available only in the minds of the Senior Engineering and Departmental officers of the airline. (Surprisingly enough, when we find ourselves short on knowledge or manpower, the aircraft manufacturer is invariably breathing down our neck just quivering to lend assistance, whether to do with his aircraft or his competitors'.) One of the rather self evident things we have found is that detailed examination of the multitude of problems invariably presents an amazing variety of solutions. However, in general we find that, when the problems are reduced to cold hard dollars, the final answer is evident and it is then perhaps the similarity, rather than the variety, which is amazing.

AIRLINE PERSONNEL STRUCTURE

Detail considerations, pertinent to the definition and selection of an aircraft, are many and varied. Because of this, many organizational groups within the airline's personnel structure are involved in and contribute to the solution of the problem.

For example, our Sales department maintain continuous records of traffic offering between all communities we serve. These records, on the theory of probabilities, are projected into the future, corrected and adjusted against such things as local economy, tourist vs first class potential and so on.

Our Operations Planning group, in addition to other functions, combine the airplane capability analysis with the traffic analysis, establish schedules and then operate these schedules as ghost airlines.

Our Purchases & Stores department constantly scrutinize, develop and experiment with warranties, contracts and material handling to establish anticipated standards which influence our costing studies.

The Engineering department maintain a current aircraft specification against both intercontinental and domestic aircraft as a basic requirement. This provides a compilation of all departments' requirements that is changed as the requirements change. They maintain an "Aircraft Evaluation Handbook", which outlines procedures and standards for analytical evaluation of any particular aircraft on routes operated by TCA and also provides a consolidated standard source for airport and route data. They also maintain an up-to-date historical record of the good and the bad associated with all aircraft we have operated or with which we have had experience.

There are other departments, of course, each concerned with a specialized function, but all aimed at providing information, data and know-how to assure that the correct aircraft and equipment are selected and scheduled into our operation.

PHYSICAL ANALYSIS

In the evaluation process and for purposes of comparative analysis between aircraft, if the capabilities of the aircraft are such as to approximately fit our requirements, we first check the physical aspects. One of our first interests in this regard is, of course, interior arrangement, that is, such things as number of seats, seating arrangement, galley accommodations, number of and location of lavatories, flight deck accommodations, instrument layout and radio and navigation facilities. Also a check is made of external dimensions against hangar sizes, ramp area, etc.

These activities are performed in appreciable detail and, while we continually seek safety, speed, economy and ease of maintenance in an airplane, in addition there is an ever increasing awareness of the passenger's need. We, in the airlines, realize that the interior accommodation of our aircraft today is measurable in terms of mid-Victorian comfort standards. This is particularly true in the design philosophy associated with the lavatories. But the correction herein is not easily attainable. As mentioned before, when we reduce each problem to point of identification and then to dollars, the solution is usually simple. For instance, just last week I was privileged to review an invoice to our airline for '1 off aircraft toilet seat $135.00'. Unbelievable, yes (!) but quite true. You, the paying customer must eventually foot this bill. What price modern convenience!

We recognize full well that today's airplanes are, by comparison with our homes, uncomfortable, poorly ventilated and extremely noisy. We can and do technically check the theoretical analysis of the manufacturer regarding noise, airflow, air changes, temperature control etc., and equate each manufacturer by comparison. But no one knows just how good the final result will be before the aircraft actually flies. Certainly we build into our purchase agreements all possible design specification limits and do our best, in conjunction with the manufacturers, to see them met. Here again, the past experience of the manufacturer, in meeting and overcoming the passenger comfort problems, bears very heavily with us in airplane selection. In spite of somewhat disappointing experiences of the past, we confidently believe the new aircraft will offer standards of passenger comfort beyond any comparison with those of today.

We then carry on to check the structural design philosophy, being always conscious of the needs of our Maintenance department who are responsible for inspection, repair and/or replacement and overhaul of components and sub assemblies. We must, at this stage, have reached a sufficiently knowledgeable position to evaluate inspection and overhaul times and evolve tentative programs, such that costing can be forecasted with reasonable accuracy. This is particularly important and cannot be too heavily stressed, as a very high proportion of our direct costs is the responsibility of the Maintenance department. We are also very aware of our obligations in attempting to evaluate the possible effects of fatigue

on the structural design philosophy. Generally speaking, the manufacturer has already done thorough stress analysis, proof loading and realistic cyclic testing. We then appraise his design in the light of our own practical experience and, on the basis of comparison, prejudge his effectiveness. We must also evaluate the effects of any new standards that may have to be introduced to the airline, such as tools, new stock items, shop and ground equipment, and their effect on capital and operating costs.

We also appraise the use of new materials and new manufacturing processes and try to add up what the cost may be when magnesium floor beams are used, or what the appearance of the aircraft will be when spot welding is used in areas that affect the passengers' aesthetic senses.

Having completed these exercises, we then compare and evaluate each systems group in the aircraft in similar fashion — wings, tail, body, surface controls, alighting gear, fuel systems, hydraulic systems, electrical and air conditioning, anti-atmospherics, radio and navigation, special systems such as oxygen, fire emergency, etc.

You have probably noticed that we have not yet fitted the aircraft with any means of propulsion. It's not really wishful thinking but rather that the power plant and engine relationship is so complex, costly, confusing and downright cantankerous, that we invariably prepare completely separate analyses of the power plant and engine before combining it with the airplane performance and costing study. The treatment given the engine and/or engines is as thorough going and exhaustive as it is for the whole mechanical study of the airplane proper. There is an exception to this, on occasion, when we find it most difficult to obtain all the desired information because of security. In such cases the engineers just have to "stick their necks out" a little further.

Our next comparative study that has been given a great deal of attention is that associated with the weight of the aircraft. While the all-up gross, zero fuel and landing weights are primarily involved with our performance and costing analysis, the determination of airplane operating weight empty has long been an extremely difficult problem. Each manufacturer has his own approach to weight and to get weights on a truly representative basis, so that fair comparison can be made, is a very difficult chore. We, as an airline, invariably add appreciable equipment to the aircraft to meet our own particular needs, in addition to changes and corrections which have to be made to the manufacturers' data. Important as weight establishment is, it can and usually does loom large as a subsequent control problem in actual operation. For example, I recall the case of an airline that, when it made its first purchase of a four-engined airliner a few years ago, arranged the usual introductory program complete with the red carpet and company and civic officials. The aircraft, with a full complement of passengers, arrived over the field on schedule, sparkling and brand spanking new, landed, taxied smartly up in front of the local dignitaries and, as the engines were cut, tipped its nose wheel in the air and settled back on its gasukas. The cause was simple and could have been foreseen and prevented.

The aircraft had been loaded slightly tail heavy and had also maintained a high rate of descent through appreciable turbulence, resulting in forty air sick passengers rushing to the rear door just as the aircraft stopped. I might add that a tree full of vultures had nothing on the interior of that aircraft.

This sort of thing can happen, of course, in the best of regulated families; however, much of it can be legislated against and/or generally avoided by adequate study and foreknowledge.

THE MANUFACTURER

During the program of evaluation of the physical aspects of the airplanes, an overall comparative appraisal of the manufacturers is made which itemizes as factually as possible what areas and degree of risk are involved.

For example, what has been our past relationship with him? How good are his delivery promises? What is his record on meeting performance and weight guarantees? How well does he meet requirements for parts interchangeability between aircraft? What are his after sales policies, and what is his financial position, and so on.

Similar comparative appraisals are made of the engine manufacturer and other special equipment suppliers.

PERFORMANCE

TCA's requirements for a trans-oceanic transport call for an airplane which must be able to carry out a non-stop service between Toronto and London, with approximately 120 passengers and 6,000 lb of airmail or cargo, at an average cruising speed of about 550 mph. The airplane must permit the use of conventional flying techniques, reserves, runways etc.

To be more precise, considering the magnitude of the winds at cruising altitudes and the normal reserves of fuel required by TCA, the airplane, to maintain a scheduled service, would have to have an equivalent still air range of about 5,500 statute miles with the required payload.

In order that no other airplane will be able to provide an appreciably faster service for some years to come, the airplane should be able to cruise at 550 mph for long ranges and up to 600 mph for short ranges.

These requirements, of course, preclude the use of turbo-propeller or piston powered airplanes as presently envisaged but, nevertheless, these airplane types must be considered, particularly if there is any indication that they would have substantially lower direct operating costs.

Before we start the actual route study for an airplane, it is necessary to determine the interior layout, weight, space and weight limit payloads etc. In calculating the operational weight empty, we assume that the manufacturer allows the weight to increase to the allowable tolerance and that TCA have a certain number of "special" modifications incorporated.

Typical assumptions for a North Atlantic route study for a turbojet transport are as follows:

(1) Start, taxi and take-off — 10 minutes.

(2) Climb at best speeds, compatible with engine manufacturer's warranties.

(3) Cruise at constant Mach number of "X" at constant altitude (different altitude bands assigned for eastbound and westbound).

(4) Descent at speeds compatible with airplane limiting speeds.
(5) Hold at 15,000 ft for one hour on four engines at a good control speed.
(6) Circuit and manoeuvre time of 5 minutes for costing purposes but fuel must be carried for 15 minutes.
(7) Climb out from airport altitude to cruising at cruising altitude.
(8) Cruise to alternate at the most economical speed.
(9) Descent as above.
(10) Circuit and manoeuvre of 10 minutes at alternate.
(11) Land.
(12) Fuel tolerance for meteorological and navigational factors, 7% of the fuel for climb, cruise and descent from origin to destination.
(13) Winds for 90% regularity when establishing the ability of the airplane to fly the route. Average winds to be used for costing purposes.

The above assumptions appear quite restrictive but we have our reasons for each one.

In the case of weight, we have never received a new airplane which has been near the weight empty originally conceived. True, a good percentage of the weight increases have been due to our own requirements, but these requirements will also be applicable to new airplane types.

The constant Mach number, constant altitude requirement may appear restrictive but we have set this as a requirement because of anticipated air traffic control problems.

If, in the early 1960's, there were no more traffic in the North Atlantic than what we have right now, air traffic control would still be a real problem. At the present time, our flights are rarely more than 10 minutes away from another commercial transport. With an estimated 50% increase in traffic, and aircraft cruising at nearly twice the speed, it is going to be difficult to keep track of the flights.

Practically every long range turbine powered transport manufacturer is selling his airplane on the basis of climbing cruise procedures, since these procedures give the greatest range. With both the turbojet and the turboprop powered airplanes, the altitude band covered with a climbing cruise is about 8,000 ft. If this procedure were used on the North Atlantic, it would necessitate fixed tracks, or lateral separation, and preclude the use of pressure pattern flying.

Theoretically, a stepped climb operation would give better range, but we know that existing congestion on the North Atlantic makes this virtually impossible. Conditions will probably be worse in the 1960's.

The holding at 15,000 ft on four engines at the destination for one hour is a practical requirement. Previous studies have been based on holding at the alternate, i.e. at the zero fuel weight. Experience has indicated that holding is done at the destination, so we analyze airplanes on this basis.

Going to the alternate from airport altitude is now becoming a universal way of studying airplanes. We have always felt that diverting to the alternate at cruising altitude is unrealistic as the flight crew must check for themselves the weather at their minimum altitude.

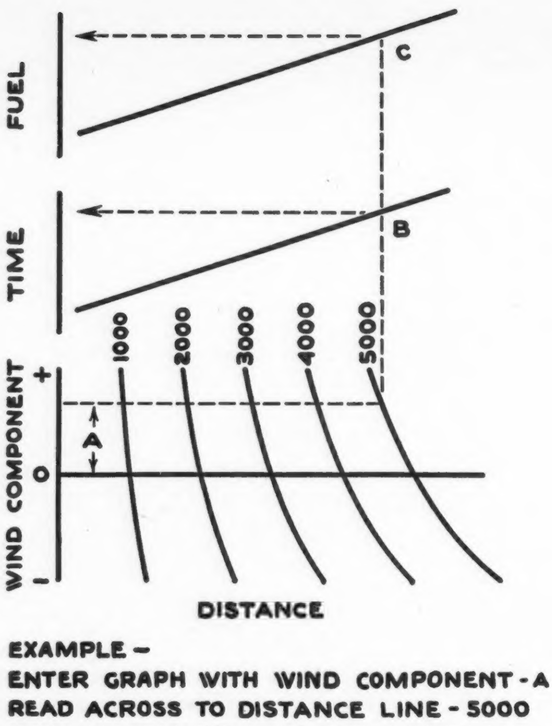


Figure 1
Turbojet time and fuel graph—constant altitude, constant Mach No.

The fuel tolerance of 7% may appear a little high, in view of some of the other assumptions, but then we assume zero tolerances on specification fuel consumption. The tolerance on specification fuel consumption may be as high as 5%.

The 90% wind assumption is necessary, since there is still too little known about jet streams. At high altitudes, what we now consider as 90% winds may only be average, when we actually get around to flying up there.

Having settled on the manner in which we would operate the airplane, we usually work out composite curves incorporating all the assumptions from which we can read block time and block fuel, for any range, wind and altitude. A typical curve is shown on Figure 1. We also draw similar curves from which we can read holding and alternate fuel.

For a simplified comparison of range and payload, curves as shown on Figure 2 are prepared. Note that, for the particular example shown, the turbo-propeller and piston powered airplanes fall short of the range requirement.

The bar chart on Figure 3 illustrates the differences in average cruising speed between typical turbojet, turboprop and piston powered airplanes.

Other obviously important factors in comparing the performance of various airplanes are approach speeds, take-off and landing runway lengths.

THEORETICAL COST STUDY

Some of our own people feel that it is a waste of time carrying out a detailed operating cost comparison between airplanes which have widely different speeds, as

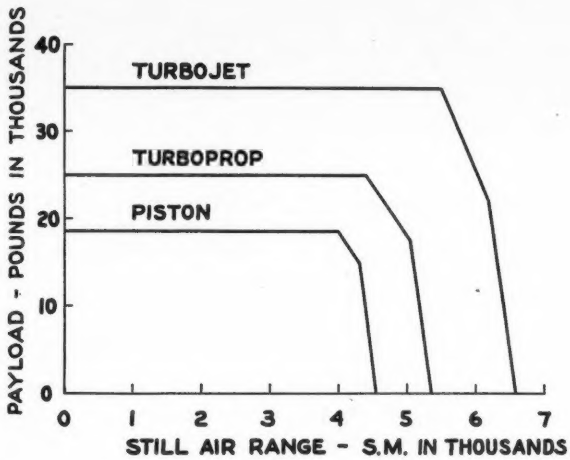


Figure 2
Typical range payload

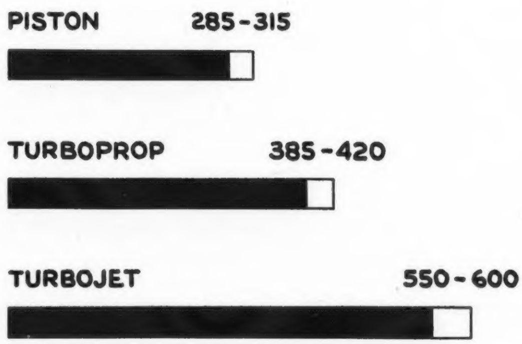


Figure 3
Typical cruising speeds—mph

they feel that the faster airplane is automatically more appealing to the public and that any direct operating cost differences would more than be compensated by the additional revenue. This fact has been borne out in the past but we must be very careful not to buy the statement blindly. Block times are becoming so low that ground time is extremely critical. It just could be that the operator with the fastest ground handling but the slowest airplane might have the most attractive operation.

In any event, we must carry out comparative operating cost studies to assure ourselves that the investment is sound. In so doing, we must be cognizant of the fact that many commodities, essential to providing air transportation, cost considerably more in Canada than elsewhere in North America. Sales tax and import duties on aircraft, ground equipment, fuel and oil, place us at an immediate dollar disadvantage. Additionally, landing fees payable by Canadian airlines are among the highest in the world. For example, the difference in dollar charge between Canada and the United States is in the ratio of 4 or 5 to 1.

I will run through quickly the method we follow in carrying out a direct operating cost comparison. Although I previously stated that our North Atlantic service would consist of route legs from Montreal and Toronto to London and Prestwick, I will confine this example to the Montreal-London leg, in the interests of simplicity.

In this example, we will use the typical turbojet, turboprop and piston powered airplanes previously mentioned. Pertinent data on these airplanes are shown on Figures 4 and 5. The passenger capacities shown are for a mixed tourist-first class version. All the airplanes could carry more people if they were 100% tourist.

We feel that it is impossible to compare airplanes on an individual basis, i.e. a single turbojet against a single turboprop powered airplane. We must compare them on a fleet basis on the routes we plan on flying and with the anticipated traffic offering.

The problem statement is, therefore:

Determine the airplane with the lowest direct operating cost per available seat mile on the London to Montreal (return) route leg using the following assumptions:

(a) 1,000 passengers mixed class each way per week,
(b) 80% passenger load factor average,
(c) winds for 90% schedule regularity when selling seat space, but average winds for costing and
(d) at least one flight each way per day with the same departure time.

The first step is to carry out a detailed route leg study for each airplane to determine the block times, consumed fuel, payload etc. The winds are considered, reserves and alternates set up etc.

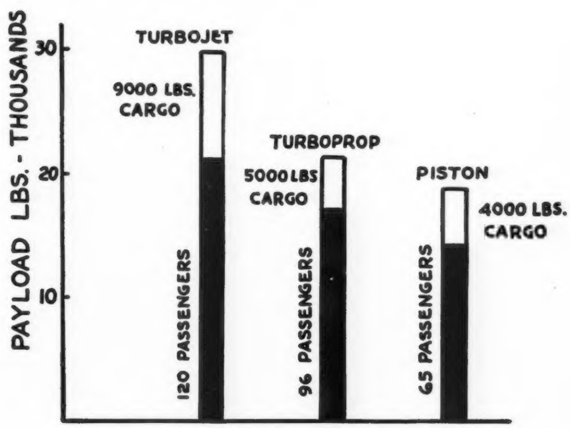


Figure 4
Payload capabilities

	TURBOJET	TURBOPROP	PISTON
WEIGHT - LB.	275,000 +	160,000 +	130,000 +
MEAN CRUISING SPEED - M.P.H.	550	385	285
NUMBER OF PASSENGERS	120	96	65
PAYLOAD - LB.	35,000	25,000	18,500
CARGO - LB.	9,000	5,000	4,000
INITIAL COST - $	5,500,000	3,700,000	2,100,000

Figure 5
Aircraft comparison

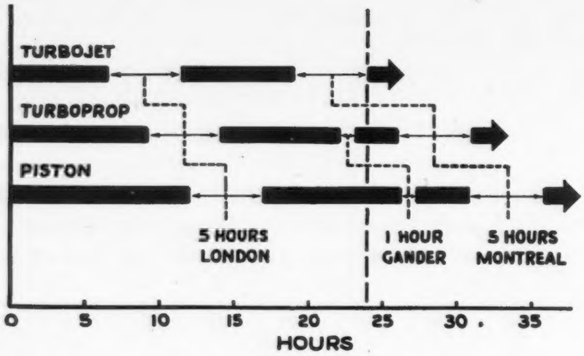


Figure 6
Flight times, Montreal-London return

Figure 6 shows the average flight times over the year for the three airplanes. The turbojet makes the round trip from Montreal to London and back to Montreal in 13 hours flying time and, considering a five hour turn-around at both ends, results in a total time of 24 hours for the cycle. Theoretically, one airplane of this type could complete 7 round trips a week. This, of course, is impracticable, since major maintenance checks are necessary and spare aircraft are required in the event of a late arrival back in Montreal.

The turboprop powered airplane, having a lower cruising speed than the turbojet, takes longer to cross the ocean and requires a stop at Goose Bay on the way back, because of the headwinds. It could fly non-stop a small percentage of the time but could only do so at reduced payload. With a 5 hour layover at each end of the route, this airplane would require 30 hours for a complete cycle.

The piston powered airplane is slower than both the other two and also has to stop on the return journey. This airplane takes 36 hours for the complete cycle.

At this point, it is necessary to set up actual operating schedules to take into account such things as preferred time of departure and arrival, scheduled maintenance checks, unscheduled unserviceabilities etc. Spare airplanes are calculated and the total number of aircraft determined. For our 1,000 passenger a week London-Montreal operation, 3 turbojets or 5 turboprops or 7 piston powered airplanes would be required.

Figure 7 summarizes the data established so far, showing also flying hours per year and daily utilization.

	TURBOJET	TURBOPROP	PISTON
PASSENGERS PER WEEK	1,000	1,000	1,000
FLIGHTS PER WEEK	10	13	19
FLYING TIME	13.1	19.1	26.0
DAILY UTILIZATION	6.25	7.05	9.45
YEARLY UTILIZATION	6,810	12,900	24,200
NUMBER OF AIRPLANES	3	5	7

Figure 7
Montreal to London and return

	TURBOJET	TURBOPROP	PISTON
YEARLY UTILIZATION	6,810	12,900	24,200
NUMBER OF AIRPLANES	3	5	7
CREW COST	479,000	786,000	1,400,000
FUEL AND OIL	2,120,000	1,560,000	3,320,000
MAINTENANCE LABOUR AND MATERIAL	1,400,000	2,100,000	2,830,000
DEPRECIATION AND INSURANCE	3,270,000	3,690,000	2,870,000
TOTAL	7,287,000	8,136,000	10,420,000

Figure 8
Summary—direct operating costs

Lacking proved costing information, other than for piston powered aircraft, we use cost formulae established by the Air Transport Association, suitably modified to our Canadian needs.

Figure 8 shows the summary of the direct operating costs for the three airplanes under consideration.

The flight crew costs per hour for the jet are based on a value 20% greater than that for the turboprop and 26% greater than that for the piston powered airplanes. These values are considerably higher than present day values and include speed and gross weight factors as dollar adjustments.

The fuel costs are based on \$0.19 per gallon for turbine fuel and \$0.31 per gallon for gasoline.

The maintenance labour & material cost per hour for the jet is about 65% greater than that for the piston powered airplane. Even at this, the yearly cost is much lower since only about 28% of the flying hours are required to do the same work load.

Depreciation is based on 7 years and insurance is based on 5% per year. Note that three turbojets at \$5,500,000 have lower depreciation and insurance than five turboprops at \$3,700,000 each.

The results show the turbojet to be about 10% cheaper than the turboprop and about 30% cheaper than the piston. We have found this to be typical on all our Atlantic routes for the airplanes considered.

The question may be asked as to the necessity of requiring 3, 5 and 7 turbojets, turboprops and piston powered airplanes respectively, when only 2, 3 and 5 are actually required to do the flying. The answer is scheduling.

The following factors must be considered in the scheduling.

(a) It is very important from the traffic standpoint to have the same departure time each day. This is quite simple with the jet since, on this particular route, it makes the round trip in 24 hours, including five hours servicing time at each end. With the turboprop and piston powered airplanes, taking 30 and 36 hours respectively, the problem is a little more complex.

(b) It is necessary to have a given number of hours elapsed time for each airplane at the overhaul base for routine maintenance. Just because an airplane has a utilization of 8 hours doesn't mean that the

remaining time is available for maintenance. Enroute stops, turn-around time etc., cannot be used for major maintenance. Sufficient airplane hours must be made available to the Maintenance department to carry out their function.

(c) Spare coverage is required for each departure out of Montreal to handle last minute unserviceabilities, late arrivals etc. Late arrivals are felt to be less likely with the jet, since no stop is required on the westbound flight. Bad weather at intermediate stops produce delays and, for some unknown reason, every stop seems to introduce additional mechanical irregularities. The turbojet airplane is less affected by winds, since its cruising speed is so high. For example, if the headwind component increased from the average component to that which was exceeded only 10% of the time (90% wind), the block time from London to Montreal would increase by only 33 minutes.

For the turboprop, the equivalent increase in block time would be one hour.

Therefore, that portion of the turn-around time which takes into consideration late arrival due to adverse winds should be less for the jet.

It may be argued that the effect of winds would cancel out on eastbound and westbound flights, so that the jet would show no particular advantage over the turboprop and piston. However, if a high tailwind permits the flight to land ahead of time, this time gain is of no advantage for scheduling purposes since departures ahead of schedule are not permitted.

If we considered all the intangible factors, we believe that the turbojet type of airplane would show advantages, other than operating costs, over the turboprop and piston powered airplanes.

For example, we think that the turbojet will realize higher load factors than the other two types, providing the three airplane types were operating on the same route simultaneously, departing at the same time and having the same class of passenger service. Past experience has indicated that, space available, the passengers will travel by the fastest means.

Another factor in favour of this particular turbojet is that it carries nearly double the cargo of the other two types. This would tend to give it more operating revenue.

On completion of this final stage, it is, of course, necessary to agree a contractual specification with the manufacturer. This is a very simple problem as each department in the airline now knows exactly what they must have in the aircraft to meet their requirements and final specification agreement is a simple matter.

OPERATIONS PLANNING

After the selection has been made, the airline is faced with the problem of preparing for and introducing the new airplane into its operation. This is perhaps a good point at which to express a word of caution and that is, we cannot and should not expect to have an economical and workable airline if we attempt to dispose of complete fleets of piston powered aircraft of two or three types and within, say, a six or eight month period introduce complete replacement by turboprop and/or turbojet aircraft. Certainly, the 1960 type aircraft cannot be

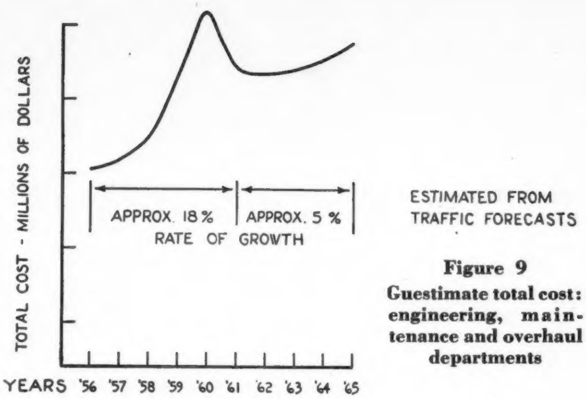


Figure 9
Guestimate total cost: engineering, maintenance and overhaul departments

suddenly substituted for the aircraft of today before a careful evaluation of this phasing in program has been completed. In the Engineering and Maintenance department alone, it appears that costs in 1960-61 could well vary between a low and a high by as much as ten million dollars (Figure 9); the magnitude of this cost bump will be determined by how efficiently and effectively we perform our job of placing these new aircraft in our operation.

Many airlines have learned this lesson the hard way in the past but now the dollars involved could well be economically catastrophic; therefore, our Operations Planning people will shortly institute a ghost airline to check each part of our program. For example, it might be of interest to note that, many months before taking delivery of our present propeller turbine aircraft, our Operations Planning people flew regular scheduled ghost operations. This whole operation, while admittedly a paper one, was handled just as our normal operation would be, prejudging and weighing the effects of all those many things that affect scheduled operation. As a result of this type of programming, the Viscount was introduced into our domestic service with far fewer teething troubles than any other aircraft in the history of the company. The same type of program, modified certainly, is being implemented now for the next breed of aircraft. It won't be long until, on paper, our ghost airline will go into regular, daily scheduled operation and a great deal will be learned to prove, disprove or modify our guesses before the first of these new aircraft actually fly.

AIRPORT DEVELOPMENT

In conclusion, I believe it desirable to just mention a few of the other very important areas of investigation in which we must actively participate, but over which we of course have no control.

Certainly some new runways will have to be built to use any airplane bigger than a DC-3; others, already in existence, will have to be lengthened or increased in strength if some of the inland cities are to be served by the big transports of the future. New, larger and more adequate terminal facilities must be provided at the majority of Canadian airports to even begin to look after the current growth of traffic. Additionally, more rapid development in the technical aids to air navigation and automatic approach aids is essential as the sky is filling with airplanes of all types.

JET ENGINE NOISE AND ASSOCIATED PROBLEMS†

by G. R. Gibson*

Avro Aircraft Limited

INTRODUCTION

SOUND is defined in the Little Oxford Dictionary as "audible air vibrations; what is or may be heard; mere noise as opposed to meaning". The development of the Science of Sound (Acoustics) has been closely associated with the growth of civilization. Sir Isaac Newton (1642-1727), who formulated so many laws of physics, is given credit for founding the theory of sound. In the early part of the 18th century, he developed the following theorem which is of fundamental importance in acoustics: "The velocity of propagation of a pulse in an elastic fluid is directly proportional to the square root of the elasticity and inversely proportional to the square root of the density". This means that vibrations will travel faster through mediums which are more elastic and slower through mediums which are more dense.

During the past few decades, the increase caused by aircraft engines to the overall noise was too small to affect our complacency. The production of energy by a machine has always resulted in the by-production of heat and noise. The quantity of heat liberated by engines has always been very high and consequently the hazard from heat was recognized at an early stage. On the other hand, the proportion of energy which was liberated as noise from the fuel of low powered engines was always very small and consequently the noise hazard was overlooked. In the jet aircraft engines of today, about 90% of the fuel energy is released as heat and about ½% as noise. Although the latter percentage may appear small, the total power which is released has become tremendous and the noise output has quickly gone into the dangerous levels.

PERCEPTION OF SOUND

The average human ear can perceive tones whose frequencies are in the range 20 to 16,000 cps and a relatively small number of people are able to hear up to 20,000 cps. The ear is most sensitive to sound in the 500 to 6,000 cps range. In this sensitive range, the wave amplitudes of the displaced particles of easily heard sound are of molecular dimensions whilst amplitudes of a fraction of a millimeter are heard as very loud noises. Sounds in this range are easily excited and difficult to eliminate. Figures 1 and 2 show audiograms for various types of hearing.[1]

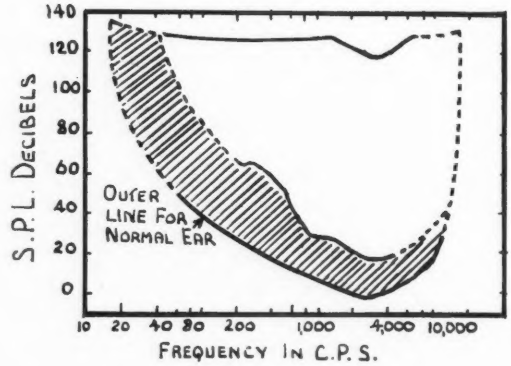


Figure 1
Audiogram of an ear deficient in hearing of low pitches

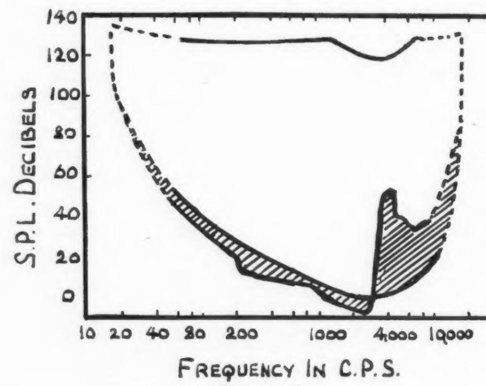


Figure 2
Audiogram of an ear deficient in hearing of high pitches

FREQUENCY AND WAVE LENGTH

The frequency of a sound is the number of complete cycles which are transmitted per second. High frequencies correspond to short wave lengths and vice versa.

$$\text{Wave length } \lambda = \frac{V}{F}$$

where V is the speed of sound and F is the frequency. Table 1 compares frequencies and wavelengths which are in the audible range.

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TABLE 1

Frequency (F) cps	50	100	300	2,500	4,000	5,000	12,000
Wave length (λ) in	264	132	44	5.3	3.3	2.6	1.1

A heterogeneous sound may be made up of superimposed waves from this entire range of wave lengths. The frequencies of these individual waves are called the component frequencies.

The wave lengths associated with a certain type of sound will determine the character of that sound. The rumbling of thunder is of long wave length, ordinary whistling is of intermediate wave length and the tinkling of a bell or the rustling of paper is of shorter wave length. The noise produced by a fan is complex; for small fans high frequencies predominate whilst for large fans a considerable proportion of low frequencies will be produced.

THE DECIBEL AND MATHEMATICAL DEFINITION

The Decibel (one-tenth of a Bel) is named in honour of Alexander Graham Bell, the inventor of the telephone, and is the unit most commonly used in the measurement of sound. The abbreviation for decibel is db. A difference of 1 db between two sound intensities is barely discernible to the ear. The decibel is not a unit like one inch or one pound but is a logarithmic ratio. The sound level is based on the ratio of the sound intensity or sound pressure being measured to the previously determined reference value. In other words, the difference in levels of the two sounds is proportional to the difference between the logarithms, to the base 10, of the sound intensity or sound pressure of the two sounds.

Table 2 shows the meaning of the sound level in terms of (a) normal sounds, (b) root mean square of rise and fall of pressure in sound waves, (c) sound intensity and (d) half amplitude of displacement of air particles in a 100 and 1,000 cps wave. The noise level scale in Table 2 is constructed so that every increase of 10 db corresponds to 10 times the noise intensity as shown in the fourth column. Thus a very loud noise of 115 db has a sound intensity which is ten billion times that of a low whisper in perfectly quiet surroundings. The scale covers the whole of the tabulated audible sound range in 100 units and distinguishes noises more as the ear actually does than would a scale based upon pressure or intensity units as given in columns 3 and 4 of Table 2.

For practical purposes it is useful to remember that every increase of 3 db in noise level means that the intensity almost exactly doubles. If one noise is 12 db greater than another, the first noise intensity must be doubled four times, i.e., multiplied by 16 to equal that of the second intensity.

The difference in decibels between two noises of intensities I_a and I_b is defined by the mathematical relation,

$$\text{difference in decibels} = 10 \operatorname{Log}_{10} \left(\frac{I_b}{I_a}\right) \tag{2}$$

$$10 \operatorname{Log}_{10} \left(\frac{P_b^2}{P_a^2}\right) = 20 \operatorname{Log}_{10} \left(\frac{P_b}{P_a}\right) \tag{3}$$

where P_a and P_b are sound pressure amplitudes corresponding to I_a and I_b. The constant in Eq. (3) is twice as large as the constant in Eq. (2) because the sound intensity is proportional to the square of the pressure amplitude.

The reference values which are normally used are approximately those of a 1,000 cps tone which is just audible and are: Reference sound intensity = 10^{-16} watts per sq cm and Reference sound pressure = 0.0002 dynes per sq cm.

ATTENUATION OF SOUND OVER DISTANCE

Consider a vibrating sound source which is at the centre of a spherical enclosure. The rate at which energy

TABLE 2

Noise level Decibels	Normal (every day) sounds	Root mean square of pressure fluctuations, dynes per sq cm	Sound intensity/Sound intensity at noise intensity level of 15 db	Half Amp (cm) of air particle displacement	
				100 cps	1000 cps
15	Low whisper	10^{-3}	1		
25	Purring cat	—	10	10^{-7}	10^{-8}
35	Turning page of newspaper	10^{-2}	10^{2}		
45	Private office	—	10^{3}	10^{-6}	10^{-7}
55	Average restaurant	10^{-1}	10^{4}		
65	Noisy office or store	—	10^{5}	10^{-5}	10^{-6}
75	Street noise, large city	1	10^{6}		
85	Noisy factory	—	10^{7}	10^{-4}	10^{-5}
95	Noisiest spot at Niagara Falls	10	10^{8}		
105	Inside subway car	—	10^{9}	10^{-3}	10^{-4}
115	Loud thunder	20	10^{10}		

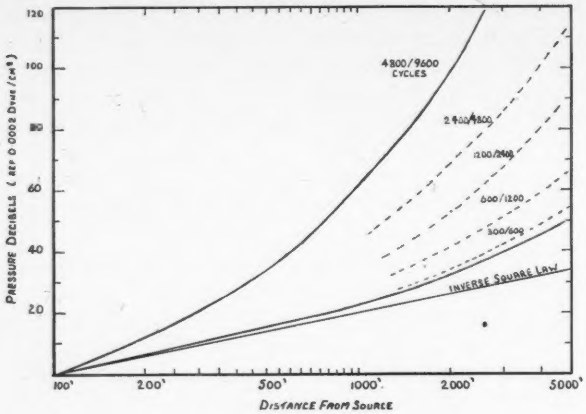

Figure 3
Attenuation of sound

leaves the source will equal the rate at which energy passes through the surface of the sphere. Therefore,

$$S = \frac{e}{4\pi r^2} \qquad (4)$$

where S is the sound intensity at the surface of the sphere, r is the radius of the sphere, and e is the energy which is radiated per unit time from the source.

Eq. (4) shows that the intensity of sound at any surface varies inversely with the square of the distance of that surface from the vibrating body. This is called the inverse square law.

Figure 3 shows curves of the decrease of sound level pressure with distance which have been compiled from a series of test readings for different frequency bands. Comparison may be made with the expected decibel drop as predicted by the inverse square law. It should be noted that noise in the higher frequency range does not carry as far as the low frequency noise.

DAMAGE TO THE AIRCRAFT AND EQUIPMENT CAUSED BY NOISE

Malfunctioning of electronic equipment is one of the many occupational hazards associated with jet engine noise. At present tests are being carried out in Great Britain and the United States to try to solve the many problems in this particular field. At the Armour Research Foundation in Chicago,[2] it was found during tests on sensitive balanced relays that 110 db sound intensity was sufficient to cause disturbance of relay contacts (i.e. increase contact resistance at certain frequencies), and that 130 db of sound was sufficient to cause closed circuits to open. Thus a balanced relay, which may become inoperative or erratic in the presence of high intensity sound at certain frequencies, might operate satisfactorily with noise of the same intensity at other frequencies. Tests on standard type relays showed that contact resistance increased in a strong sound field although not to the point of opening up the contacts.

Tests on electron tubes indicate that, when subjected to high-intensity (120 db) sound, tube noise (microphonism) approaches or exceeds allowable JAN Specification limits. It can be assumed from these tests that serious consideration must be given to electronic equipment stowage areas on future aircraft to ensure that equipment of this type is at no time subjected to high-intensity noise from the jet stream or (by way of direct transmission) from the engine assembly.

The airframe structure may be considerably affected by aerodynamic noise, which may cause structural fatigue in highly stressed components. No doubt a considerable amount of information exists on noise fatigue although there has been little published on the subject. Perhaps two of the most systematic studies along these lines are by the Martin Aircraft Co.[3] and the Northrop Aircraft Inc.[4] In order to study some of the variables in the problem of fatigue due to noise, the Langley Laboratory of the N.A.C.A.[5] has recently tested a number of panels with an intense noise of discrete frequency produced by an air chopper. The panel, 11″ × 13″ × 0.032″ 2024T3 Alclad, was fastened to a rigid frame with round head screws and it was found possible to destroy this panel structure by driving it at its first resonant frequency, at intensities of 160 db, for just over one minute. However, a similar panel was subjected to 5 hours of 140 db intensity at the same resonant frequency without showing any signs of failing. It should be noted that these tests were made at the panel's resonant frequency, where damage by sound intensity is considered to be at its maximum.

The main areas of fatigue seem to predominate around the tail structure and inspection of the complete tail unit for fatigue (cracks etc.) should be part of the scheduled inspection procedure. It has been found that noise effect is most serious under ground running conditions and it may be necessary to curtail the ground running of jet engined aircraft.

PHYSIOLOGICAL PHENOMENA

To place the problem of the effect of noise on the average person into its right perspective, reference should be made to Figure 4, which shows the noise levels at which various physiological phenomena occur in an average person.[6] In this curve it is seen that, when a noise level of over 80 db is produced, conversation becomes laboured; that at 120 db definite discomfort sets in; that at 140 db actual pain is to be observed and that at 160 db mechanical damage to the inner ear is caused with permanent damage to the person concerned. In addition to the specific effect on the ear, persons subjected to a noise field of over 140 db for a period of time can suffer the following effects:

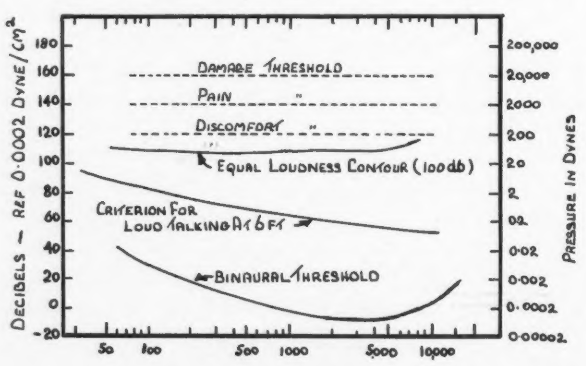

Figure 4
Noise levels at which various physiological phenomena occur in an average person

(1) Interference with orientation and coordination.
(2) Lowering of personal efficiency.
(3) Damage to body tissues.
(4) Complete loss of voice communication.
(5) Interference with senses of touch, vision, etc.
(6) Long term cumulative impairment of brain functions.
(7) Short term effects such as loss of sleep, psychosomatic or neuro-psychiatric symptoms.
(8) Interference with the performance of skilled tasks.

The conclusion to be drawn from this figure is that it is inadvisable to allow workers to operate for any length of time in a (high frequency) noise level above 85 db, although higher levels can be tolerated for short periods.

PERSONNEL

Selection of proper personnel and protection of the individual worker are two possible methods of getting maximum working efficiency with a reduction in liability. There is certainly such a thing as individual susceptibility to noise. Pre-employment testing of workers who will be in high-intensity sound fields is mandatory in order to determine this individual susceptibility. Hearing efficiency in noise is only secondary to susceptibility as a determinant factor of employment. There are some skilled individuals who have impaired hearing at low noise levels but who have high hearing efficiencies in high noise levels and who are apparently not susceptible to high noise levels. These individuals are therefore acceptable for employment from both standpoints.

Much work has been devoted in the past few years to individual protective devices and some excellent ones have been developed. These include ear defenders (both insert and cup type) and snug fitting, padded helmets. These devices have been found to be most efficient when properly fitted, although a certain element of inconvenience and discomfort from prolonged use is still present. In contrast to popular opinion, the wearing of such devices does not decrease hearing efficiency in noise but a more favourable signal-to-noise ratio may be obtained by depressing the masking levels of noise. The medical department of a company or service, engaged in work on engines within the higher intensity noise field, will have a great responsibility for the proper fitting of recommended devices and indoctrinating the wearer in the uses and advantages to be gained by wearing them as well as the dangers of discarding them. There is quite a change in the aural cues a mechanic receives while wearing ear plugs. This will not bother the new man, who will wear his ear defenders from the beginning, but the experienced worker (at present in the firm's employment) will have to retrain his ear until the new cues are established.

If Figure 5 is consulted (showing a cross-section of the human ear) the possibility can be observed of a high decibel reading sound wave getting through to the inner ear, even after insert type ear defenders have been fitted in the apertures to the tympanum. In a brief description, it could be said that the human ear consists of the auricles or pinnae, the canal with the eardrum at the end of it, the middle ear with the three little bones or ossicles and the inner ear with the liquid-filled cochlea containing the basilar membrane which is presumably the seat of audi-

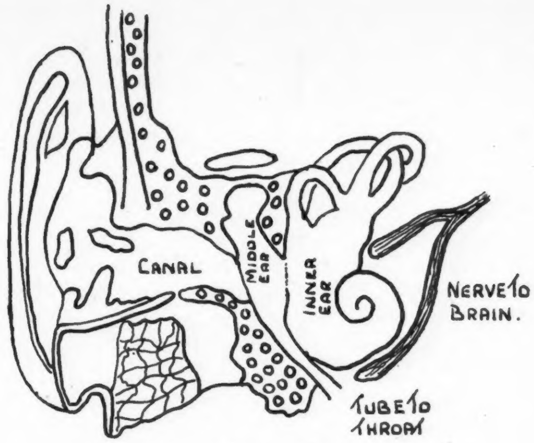

Figure 5
Cross section of the human ear

tory process. Sounds passing through the canal are communicated to the inner ear via the drum and ossicles. The actual mechanism of audition is still a subject of much investigation and there are several theories of hearing, the chief of which is still that of Helmholtz[7] which assigns resonance characteristics to the fibres in basilar membrane.

In addition to reducing noise intensity levels by wearing protective devices, it is possible to reduce the incidence of acoustic trauma by considering the time element of exposure to noise. A compromise between exposure periods and breaks in a quiet area must be worked out on a short as well as a long term basis. This means that multiple breaks must be given during the day and, after several months of exposure, a transfer must be made to a quieter working area for a period of several days or weeks. On a long term basis, such a practice will give a greater overall level of efficiency in the maintenance of aircraft.

It will be extremely important to institute a system of checking maintenance workers on the overall hearing picture of each individual. This periodic check will give a basis for advising on rest periods, both in frequency and duration, and to see whether individual protective devices have been used as recommended.

PREVENTION OF NOISE ANNOYANCE

Theoretically, there are two main solutions to the problem:

(1) keep the noise from reaching the people and
(2) eliminate the noise at its source.

Keep the noise from reaching the people

The first possibility itself breaks down into three parts. Noise can be stopped by (a) insulation, (b) absorption or (c) segregation.

Insulation prevents the travel of noise by deflecting it. Such deflection can be achieved through the use of portable or fixed shields, barriers etc. It can be achieved in the future by planning hangars and terminal buildings so that they shield against the transmission of noise during testing, taxiing and take-off run. In Britain, an acoustic wall, 40′ × 250′, has been used for aircraft running up. It was constructed at a cost of $54,400 but like all barriers it is good only under certain conditions.

Absorption definitely is a solution but only for engine noise produced on ground run-up. For taxiing, take-off, landing and traffic circle noise, other means of reduction must be devised which do not require equipment as bulky as absorptive units. The run-up cell has proved to be the most efficient unit in engine noise prevention and must be specially designed to fit a particular aeroplane. Its overall size is determined by the plane's size. For example, the Kittell-Lacy run-up cell for the Douglas F4D Skyray is a reinforced concrete structure with a 60′ × 80′ main room that is 25′ high. The walls vary in thickness from 8″ around the aircraft enclosure to 18″ in the exhaust stack section. This increase in wall thickness is required not only for structural strength, but also because of the higher noise levels in the exhaust silencer section.

An 8″ thick concrete door is contoured to fit snugly around the irregularly shaped fuselage of the F4D just aft of the cockpit. It consists of four 8′ sections mounted on tracks. The door is sealed at the top, bottom and joints by pneumatically operated butt-type rubber seals. Since the door is built in sections, it can be partly open during low power runs.

There are four main design considerations for test cells — acoustics, aerodynamics, temperature and erosion of acoustic installation through air flow. One Kittell-Lacy run-up cell reduced noise intensity from 160 db to 98 db, about a 1,600,000 : 1 reduction.

In one case, a cell had to be designed to handle jet exhaust temperatures during after-burner operation of well over 2,500°F. A cooling water cross was installed just aft of the tail cone to lower these temperatures. It was electronically controlled and cooled the exhaust flow sufficiently so that the silencing installation would suffer no damage. The control is fast enough to prevent condensation occuring during the starting and ending of burning operations. The system includes a water tank and pump capable of discharging 800 gpm through the orifices in the cross.

There are four main sources of jet engine noise (in order of importance for turbojets): aerodynamic generation of noise in the exhaust, compressor whine, internal engine noise, including turbine and combustion noise, and aerodynamic generation of noise in the inlet.

Exhaust noise is caused primarily by turbulence in the exhaust flow aft of the engine (see Figure 6). At high nozzle pressure ratios, the dimensions of supersonic and subsonic ranges of the exhaust jet stream may be of the order of 10 diameters of length for the supersonic portion and 30 diameters of length for the total wake length producing noise. Subsonically, noise increases as V^8 and supersonically as V^{14} or higher powers up to V^{20}. Very little information is available to show how the noise increases with mass flow but there can be no doubt that, for a given total of thrust, a very great reduction can be obtained by reducing the jet velocity, even by a very small amount.[8] This law is the underlying reason for the vast increase of noise associated with re-heat. The high frequencies are generated near the exhaust nozzle and the low frequencies further downstream. The source of noise may also be increased by improper engine combustion since rough burning causes more turbulence in the exhaust flow.

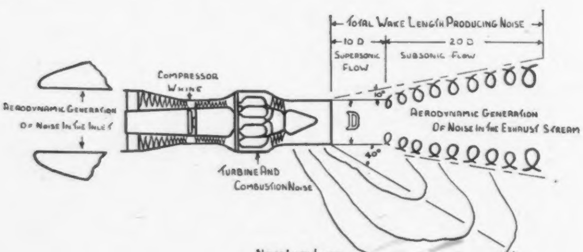

Figure 6
Jet engine noise source and turbulence locations

Compressor whine and inlet noise must be considered together. Compressor whine mainly results because there is a discrete frequency which is related to the engine rpm and the number of blades in the first stage of the compressor. Inlet noise results from the rush of air into the inlet duct of the aircraft.

One way of silencing these noises is to direct the incoming primary air through high frequency splitter panels mounted on the centre door sections. The incoming secondary air enters the enclosure from the sides and is silenced by broad band splitter panels. A tolerable amount of noise comes from the combustion chamber, owing to the relatively thin wall construction of the aircraft, and from several minor sources in the engine. These noises are often ignored in silencing.

Acoustic treatment is used on the interior wall surfaces of the test cell to reduce the sound level within the structure. This treatment also minimizes the standing wave patterns that may injure the plane's structure which is within the enclosure. The sound-absorbing materials generally used in the engine test cells are copper, rock or stainless steel wool.

Segregation is the last of the three specific means for "keeping the noise away from the people" and by this method an aircraft would be required to operate from some remote location out in the country, many miles from the nearest town. It would be restricted to flying above a certain minimum height, say 5,000′, at all times, except in the immediate vicinity of the airport. However, the disadvantages of an arrangement such as this are formidable.

Eliminate noise at the source

The real solution is to eliminate the noise at its source. At the moment, this solution can only be little more than a compromise but acousticians are working on the problem in conjunction with the Air Force and other government agencies. They cannot say with any assurance that the problem can be solved but they insist that not enough is known about jet noise at this time to say that it cannot be solved.

These possibilities of tackling the source are being explored in Britain with full scale tests already under way at Rolls-Royce.[9] One method featuring corrugations placed around the rim of the tail pipe (see Figure 7),[10] apparently is working out quite well and the first satisfactory result was a test bed run which showed that it had no effect whatever on the engine performance and produced a marked reduction in noise, as much as 10 db at the higher frequencies. A whole series of these cor-

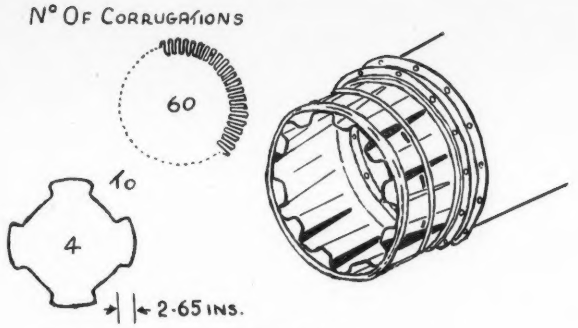

Figure 7
Corrugations placed around the rim of the tail pipe

rugated nozzles were made and tested with different numbers of corrugations on each nozzle. It was found that the peak value of the attenuation was slightly reduced with the smaller number of corrugations, but the frequency at which this peak occurs is reduced almost directly in proportion.

COMMUNITY RESPONSE

Criteria for determining what noise levels cause annoyance to people are presently being developed on a statistical basis by the U.S. Air Force. While it is not currently possible to rate annoyance itself quantitatively, it is possible to collect statistics from which the probable response of a community to a noise can be evaluated. This response can be scaled through a range which includes no annoyance, mild annoyance, mild complaints, strong complaints, threats of legal action and vigorous legal action. One method of presenting these data has been used in Figures 8 and 9 and is based on the U.S. Air Force statistics. A noise rating curve is chosen by letters to correspond to a community reaction. Choice is based on such factors as type of noise, duration and frequency of occurrence, time of day, type of neighbourhood and previous noise exposure of neighbourhood etc.

As an example of the use of these data, consider the maximum noise created by a jet aircraft of 5,000 lb static thrust, being run at maximum power, approximately 10,000 ft from a suburban community with little noise exposure history. If these data are plotted, superimposed on the curves in Figure 8, it can be seen that the noise extends into rank "Gamma". This figure applies to more or less continuous noise exposure. Assuming only about 1 to 10 exposures per hour, it has been found that the level rank can be down-graded to about "Beta". Now entering Figure 9 at "Beta", it can be seen that the probable community reaction is somewhere between "no annoyance" and "mild annoyance".

Also superimposed on these level rank curves is the expected noise level for a jet engine developing approximately 20,000 lb static thrust at 10,000 ft from the same suburban community (see Figure 8) and it can be taken that this aircraft, with engine at maximum power, will be well over the noise level rank for "vigorous legal action".

Figure 10 represents the estimated noise level range (1,000 cps octave frequency band) of several different types of jet engines, measured 150 ft at an angle of 40° from the plane of the exhaust nozzle.

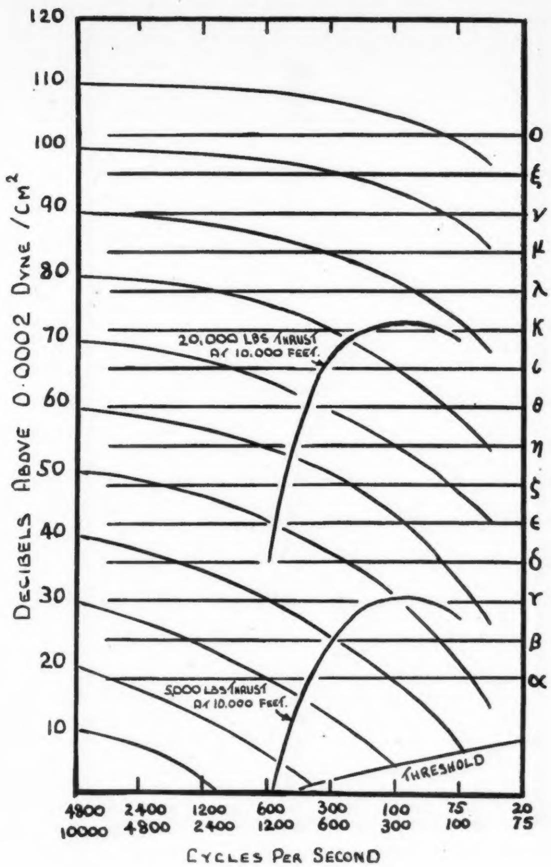

Figure 8
Community response chart

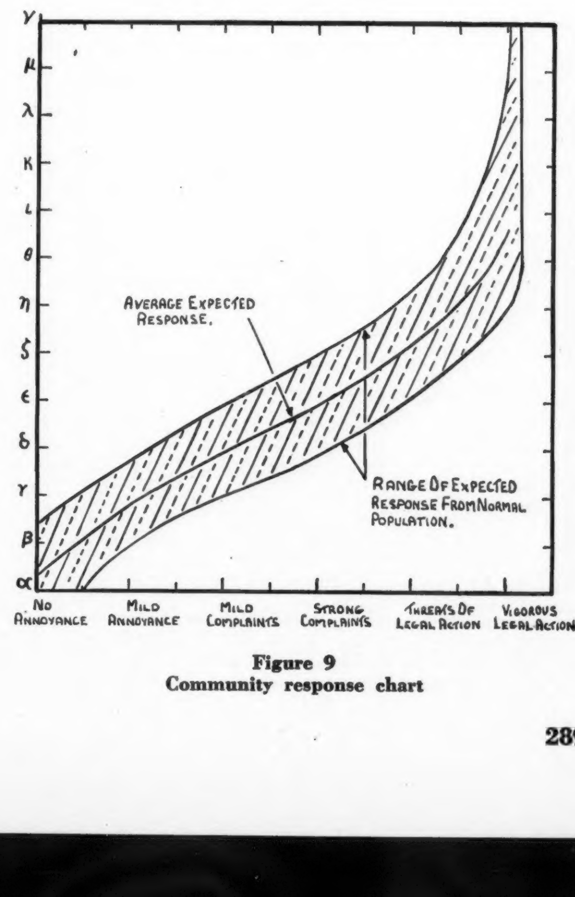

Figure 9
Community response chart

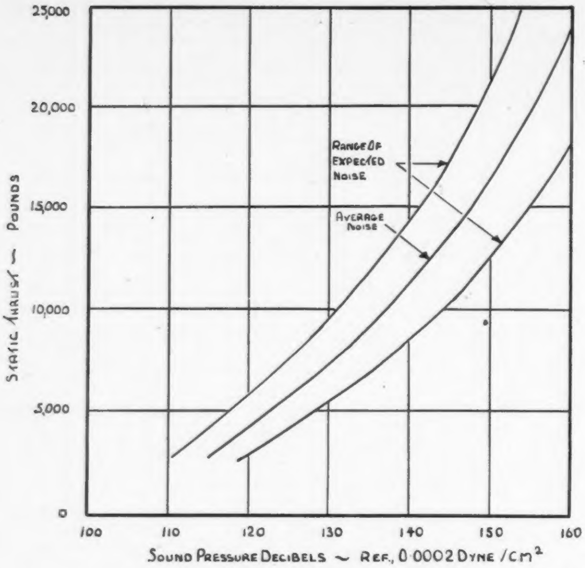

Figure 10
Sound pressure decibels vs static thrust

CONCLUSIONS

(a) Sound intensity at a point is the average rate of flow of sound energy per unit area normal to the direction of propagation of the wave. Sound pressure is the root mean square of the pressure fluctuations. In practice, sound intensities and sound pressures are compared with reference sound intensities and sound pressures by means of a logarithmic scale. The units are termed decibels.

(b) A noise level of 160 db can cause complete structural fatigue to a 11″ × 13″ × 0.32″ 2024T3 Alclad panel in approximately 1 minute if the noise is being transmitted at the panel's resonant frequency.

(c) Mechanical damage to the inner ear can be caused by a noise level of approximately 160 db, causing permanent damage to the person concerned.

(d) The shift in medical emphasis today is towards selection and protection of the ground maintenance worker. The personal equipment available is fairly adequate but can certainly stand improvement.

(e) Although the test cell answers the problem for ground running, there is no method at present available which will reduce aircraft taxiing and take-off noise to any great extent. The answer to this problem seems to be for an arrangement to operate all aircraft, which cause noise annoyance, from some remotely located airdrome.

(f) It is now generally accepted that the sound energy produced by a jet engine varies as the 8th power of the jet velocity for subsonic flows. Supersonic flows cause variations of V^{14} up to V^{29} depending on the Mach number of the jet velocity; the decibel level, of course, varies as the logarithm of the energy level. There is evidence that, while the higher frequency noise is set up near the jet orifice, low frequency noises emanate from the large scale burbling of the jet downstream.

(g) While fundamental work at universities and elsewhere has progressed most satisfactorily in providing much sought-after knowledge on the mechanisms underlying the production of noise, no practical suppression techniques have yet been put forward which reduce the noise at source, on standard type jets, by more than 9 or 10 db.

(h) The operation of an aircraft, powered by a 20,000 lb static thrust engine, will present many problems, particularly if operating from a civilian airdrome. These problems will arise during take-off, landing and traffic circle stacking.

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AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF SURFACE ROUGHNESS ON THE DRAG OF A CONE-CYLINDER MODEL AT A MACH NUMBER OF 2.48†

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SUMMARY

Experiments were conducted to determine the effect of surface roughness on the turbulent skin friction in supersonic flow, in the absence of appreciable heat transfer. The tests were made using a 20° cone-cylinder model, the cylinder of which could be replaced by others with different surface roughness.

The skin friction was determined for the cylindrical portion of the model by taking direct force measurements on the cone and then the cone-cylinder model using an internal strain gauge balance. The force tests were carried out at a nominal Mach number of 2.48 and a Reynolds number of 3.0×10^6 per foot based on free stream conditions.

The roughness effects were produced by an approximate V-thread cut into the surface of the cylinder. The scale of roughness covered by the tests ranged from 6-10,000 microinches, based on the average peak-to-valley height.

It was found that the rough cylinders exhibited no increase in friction over that of the smooth cylinders for roughness below the range 800-1000 microinches. Beyond this critical roughness the skin friction increased rapidly with roughness height. This critical roughness range is about 30 percent lower than the value obtained experimentally in incompressible flow when the comparison is made using wall values of the flow parameters. The results showed that the critical height of the roughness was about one quarter the height attributed to the laminar sublayer.

INTRODUCTION

In 1933 Nikuradse determined experimentally the laws of variation of skin friction with surface roughness in incompressible flow.[1] Nikuradse's results were obtained from tests conducted on the effect of sand grain roughness on the flow of water through a pipe and were later adapted to plate flow by Prandtl and Schlichting.[2] These results form the basis of practically all the work that has been carried out on the effect of surface roughness on drag. An example of such work is that reported by Young, Green and Young[3] in which the effect of paint roughness on the profile drag of an aerofoil was investigated at high subsonic Mach numbers.

Although considerable literature is available on the characteristics of the laminar and turbulent boundary layers over smooth models in supersonic flow, only meagre information exists on the effect of surface roughness above $M = 1$. One of the few results obtained on the effect of surface roughness in supersonic flow is given in Reference 4, which reported on the effect of distributed surface roughness on the drag of a body of revolution at $M = 1.61$.[a]

The present paper presents the essential results of the work carried out on the effect of surface roughness on the drag of a cone-cylinder model mounted at zero angle of attack in the supersonic wind tunnel at the Institute of Aerophysics.[5] The tests were made at a nominal Mach number of 2.48 and a Reynolds number of approximately 5 million, based on the length of the cylindrical part of the model. The boundary layer over the cylinder was made fully turbulent by the action of a trip placed near the apex of the cone. The distributed surface roughness covering the entire cylinder was formed by a rough V-thread. The force measurements covered a range of roughness from 6 to 10,000 microinches, based on the average peak-to-valley distance of the thread profile.

The method used in calculating the average skin friction coefficients from direct drag measurements was similar to that used by Chapman and Kester.[6]

LIST OF SYMBOLS

A	area (square inch)
C_F	average skin friction coefficient $= \dfrac{\text{force}}{\frac{1}{2}\rho_1 U_1^2 A}$
C_f	local skin friction coefficient $= \dfrac{\tau_w}{\frac{1}{2}\rho_1 U_1^2}$
D	drag
D_T	total drag (measured by balance)
D_b	base drag $= (P_b - P_1)\,\pi d^2/4$
d	cylinder diameter
f	friction force on length l
Δf	friction force on length Δl

[a]The author has just received two new reports on the effect of surface roughness in supersonic flow (References 16 and 17). Reference 16 is a theoretical analysis of the effects of three-dimensional surface roughness on the turbulent boundary layer in compressible flow with zero heat transfer; while Reference 17 deals with turbulent boundary layer and skin friction measurements on an artificially roughened, thermally insulated flat plate at supersonic speeds. Although the reports are of considerable interest they are not immediately applicable to the present work.

†Paper read before the Annual General Meeting of the C.A.I. in Montreal on the 4th May, 1956. This paper is essentially a condensation of UTIA Report No. 34, cited as Reference 5.

*Aerodynamics Engineer. This paper was written when Dr. Wade was Research Assistant, Institute of Aerophysics, University of Toronto.

K	average roughness height peak-to-valley (defined under Table 2)
K_c	critical roughness height peak-to-valley
K_{ad}	admissible roughness – three-dimensional (see Figure 9)
$k_{C.L.A.}$	centre line average roughness height (defined under Table 2)
$k_{R.M.S.}$	root mean square roughness height (defined under Table 2)
L	corrected length of cylinder ($l + \Delta l$)
l	length of cylinder
Δl	length of cylinder required to prodnce finite boundary layer thickness at Station A.
M	Mach number
P	pressure (P_a = 760 mm Hg)
R	gas constant
R_e	Reynolds number
R_e/L	Reynolds number per foot
T	Temperature °R ($T_o = 519°R$)
U	velocity free stream (ft/sec)
u	velocity boundary layer (ft/sec)
y	distance perpendicular to model
δ	boundary layer thickness
θ	boundary layer momentum thickness

$$= \int_0^\infty \frac{\rho u}{\rho_1 U_1}\left(1 - \frac{u}{U_1}\right)\left(1 + \frac{2y}{d}\right) dy$$

μ''	microinch (10^{-6} inches)
ρ	density (ρ_o = .002378 slugs/cu ft)
τ	shearing stress
υ	kinematic viscosity (μ/ρ)
μ	coefficient of viscosity

Subscripts

A	station A (start of cylinder)
a	atmospheric conditions
b	base
c	cone
c-c	cone-cylinder
i	incompressible
l	laminar
T	total
t	turbulent
w	wall or surface value
o	reservoir, total or stagnation, e.g., P_o = inlet stagnation pressure
1	state upstream of shock wave
2	state downstream of shock wave

EXPERIMENTAL EQUIPMENT AND TECHNIQUES

General

The experimental work was carried out in the 16″ × 16″ intermittent wind tunnel,[7] which operates from atmospheric inlet conditions and has a free stream Reynolds number of 3×10^6 per foot at $M_1 = 2.48$.

The Mach number distribution taken along the centre line of the tunnel over the entire model length is shown in Figure 1. The turbulence level in the tunnel is unknown, but the general flow conditions at $M_1 = 2.48$ produce a transition Reynolds number on a 10° solid cone of 2.8×10^6. The transition data was obtained from an analysis of spark-schlieren photographs.

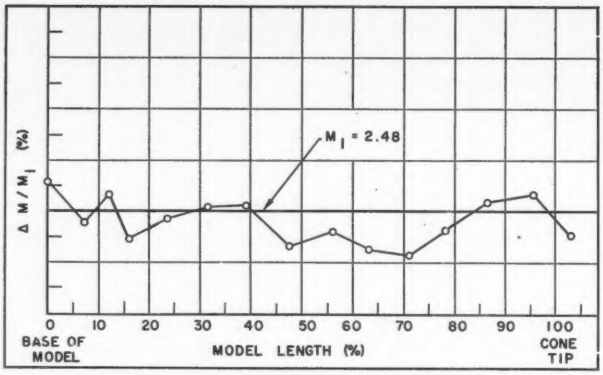


Figure 1
Mach number distribution on tunnel centre line

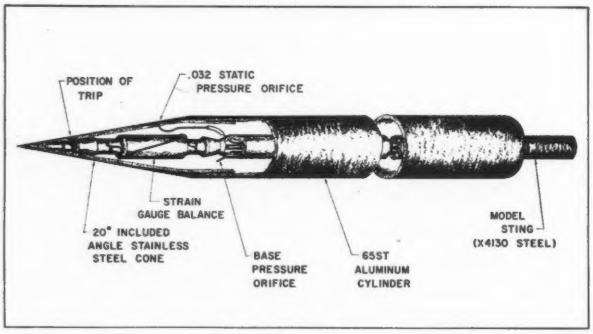


Figure 2
Schematic diagram of cone-cylinder model used in the force and pressure measurements

The force measurements were made on a cone-cylinder model using a three-component strain gauge balance mounted in the cone forebody. The general details of the model are shown in Figure 2. The method of measuring the skin friction over the cylindrical portion of the body was similar to that used by Chapman and Kester.[6] Briefly, the total drag and base pressure were measured on the cone and then the cone-cylinder configuration. An analysis of the loads on the model yields the relation:

$$\text{DRAG}_{\text{friction}} = (D_{T_{c\text{-}c}} - D_{b_{c\text{-}c}}) - (D_{T_c} - D_{b_c}) \qquad (1)$$

Production and Measurement of Surface Roughness

The type of roughness used on the cylinder part of the model was that produced by cutting a rough V-thread into the surface of the cylinder at right angles to the axis of symmetry. To provide a datum at the low end of the roughness scale, some models were made with "superfinished" surfaces. The technique of superfinish[8] is a method of mechanically developing on metal parts a surface finish which is optically smooth and metallurgically free of any fragment or smear metal.

The surface texture of the cylinders was measured using four different stylus-type surface measuring instruments.

(i) Philips roughness tester PR 9150
(ii) Profilometer model QA
(iii) Brush surface analyzer model BL-103
(iv) Taylor-Hobson model 3 Talysurf

Table 1

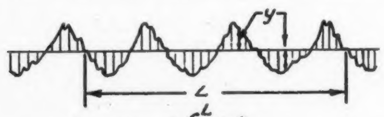
Make of Instrument	Type, Laboratory and/or Portable	Method of Generating Signal	Operation of Tracer Head	Stylus Tip Radius in.	Wave Length of Cut-off	Type of Measurement	Range of Measurement μ''	Length of Trace
Philips PR 9150	Portable	Piezo-Electric Used as a Potential Generating Device	Hand Operated	0.0024	Variable Depending on Scanning Speed, $\simeq$ 0.030″ for the Range 10–250μ''	C.L.A. (Meter)	0–280	Approximately 1″
Profilometer Model QA	Portable And Lab	Moving Coil Used as a Current Generating Device	Hand or Motor Driven	0.0005	0.030″	R.M.S. and C.L.A. (Meter)	0–1000	Variable ⅛″ to ¾″
Brush Model BL–103	Lab	Piezo-Electric	Motor Driven	0.0005	—	R.M.S. (Meter) and Actual Surface Profile by Direct Inking Oscillograph	0–100 (R.M.S.), 0–2000 Peak to Valley	Fixed ⅛″
Talysurf Model 3	Lab	Differential Airgap Inductance Acting to Modulate a Carrier Wave	Motor Driven	0.0001	0.01″ 0.03″ 0.10″	C.L.A. (Meter) and Actual Surface Profile by Recording Oscillograph	0–100 C.L.A., 0–2000 Peak to Valley	Variable ½″ Max

The general specifications of the instruments used in the surface analysis are shown in Table 1.

It was not intended to cover the complete field of surface analyzers but to obtain a series of measurements using a cross section of the equipment readily available. A preliminary study of surface measuring equipment showed that most of the instruments were unable to handle the full range of roughness under investigation. Also some of the instruments were designed to measure only one roughness parameter. It was considered essential to obtain both a centre line measurement (C.L.A. or R.M.S.) and a peak-to-valley measurement on each cylinder. The Philips and Profilometer testers permitted only a centre-line-average measurement. The Brush and Talysurf instruments were equipped with recording oscillographs, so that in addition to a numerical assessment of the surface roughness the instruments provided a graph showing a cross section of the surface contours. The average peak-to-valley distances for the cylinders were measured directly off the oscillograph charts. The

Table 2

1 Cylinder	2 Number of Threads Per Inch	3 Measurements Taken With Philips PR 9150	4 Profilometer Type QA	5 Brush BL–103		6 Talysurf Model 3		7 Comparator		8*** Range of C.L.A. Readings	9*** Range of Peak to Valley Readings	10 Average of Column 9
		C.L.A.	C.L.A.	R.M.S.**	P. to V.†	C.L.A.	P. to V.†	C.L.A.	P. to V.†			
1	–	2.0	1.5	1.0	10	.80	4.0			.60 – 2.0	4 – 10	7. ±30%
1A	–	1.8	1.5	1.0	10	1.0	6.0			.80 – 1.8	6 – 10	8. ±20%
2	*	21.	23.	21.	140	24.	80.			19. – 25.	80 – 140	110. ±20%
3	128	53.	50.	40.	500	55.	400.			35. – 60.	400 – 500	450. ±10%
4	184	60.	80.	100.	850	95.	575.			70. – 90.	650 – 850	750. ±12%
5	184	–	380.	375.	1800	–	2000.		2900	325. – 500.	1800 – 3000	2400. ±20%
6	184	–	600.	–	–	–	–		6330	500. – 625.	6000 – 6600	6300. ± 5%
7	144	–	975.	–	–	–	–		9800	950. – 1000.	9100 – 10500	9800. ± 7%



$$k_{C.L.A.} = \frac{1}{L}\int_0^L |y|\,dL$$

$$k_{RMS} = \sqrt{\frac{1}{L}\int_0^L y^2\,dL}$$

NOTE

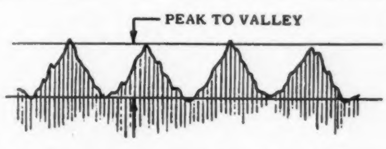
All values are in microinches.

All readings in columns 3 to 7 are the average values of 8 readings.

* Fine turned.

** R.M.S. value is approximately 10 to 20 percent greater than C.L.A. depending on wave form.

*** Maximum and minimum values obtained using all instruments.



† The peak-to-valley distance was obtained by taking the average of a number of readings from the recorder charts and comparator profiles.

Talysurf is one of the newest and most advanced instruments of its type, giving both an average measurement and an excellent graphical reproduction of the surface texture. As mentioned previously, the surface analyzers were not able to cover the entire range of test specimens; in order to obtain a profile measurement on the rough cylinders an optical comparator was used. A compilation of the surface roughness measurements is shown in Table 2. The table also shows the spread of the measurements obtained using the various surface measuring instruments.

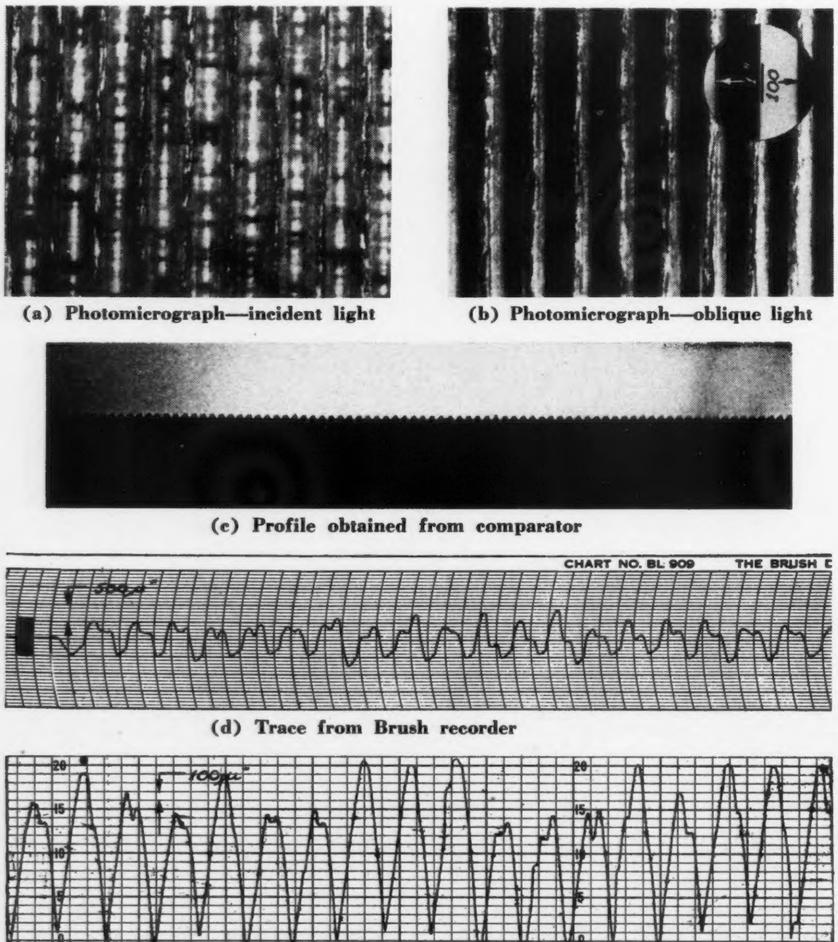
The topography of the cylindrical surfaces was also examined with the aid of a Leitz Ortholux binocular microscope using both normally incident and 45° oblique lighting. The magnification factor of approximately 50X was checked by photographing a Ronchi grating (100 lines to the inch) under the same conditions as the test specimen.

A composite picture of the roughness details on a typical cylinder (No. 5) is shown in Figure 3. Illustrating the details on this cylinder are two photomicrographs, a representative section of the charts obtained from the Brush and Talysurf recording oscillographs, and a silhouette of the V-thread profile obtained from the optical comparator.

One important consideration became apparent during the measurement of surface roughness. It has been the practice in a few cases to convert average values to maximum or peak-to-valley distances by dividing by 0.707. This implies that the roughness is sinusoidal in nature. This type of analysis may have some justification when treating waviness but, as the present results show, it is an extremely loose assumption when applied to surface roughness. The ratio between the maximum and average value, which might be termed a form factor of the surface roughness, is shown in Table 3, column 4, and for these tests lies between 4.4 and 11 with an average value of about 8. It would appear that no weight should be placed on the peak-to-valley distances obtained from average values unless the wave form is known.

The measurement of surface roughness requires a great deal of personal judgment. The figures obtained with one instrument may differ markedly with the results obtained using another instrument, since the sampling length, stylus tip profile and traversing speed are all effective parameters in the final result. Some of the measuring instruments can have an inherent inaccuracy as much as ± 30% and this is one reason why several instruments were used. The three essential factors in an assessment of a surface are the method of assessment, the sampling length and the number itself. As shown in Tables 1 and 2, the assessment method included C.L.A., R.M.S. and peak-to-valley roughness heights. The sampling length has also been quoted when available. Columns 8 and 9 of Table 2 show the maximum spread of the surface measurements and, while the difference between the maximum and minimum figures is in some instances considerable, the figures represent, it is felt, a typical set of surface measurements.

As a result of a preliminary survey into the measurement of surface roughness by stylus-type measuring instruments and the experience gained in the measurement of the surface roughness specimens for Reference 5, the superiority of the Taylor-Hobson Talysurf in reproducing graphically the peak-to-valley contours of a surface was very evident. This instrument, with its unique method of signal generation, variable cut-off wave length and wide range of accessories, is extremely versatile in the range 0-2000 microinches peak-to-valley.



(a) Photomicrograph—incident light

(b) Photomicrograph—oblique light

(c) Profile obtained from comparator

(d) Trace from Brush recorder

(e) Trace from Talysurf recorder

Figure 3
The surface conditions on cylinder No. 5

TABLE 3

1	2*	3*	4	5	6**	7***
Cylinder No.	Roughness Height C.L.A. (k)	Roughness Height Peak to Valley (K)	Form Factor K/k	C_F Measured	C_F Adjusted	C_F/C_{F_i}
1	1	7	7	0.00224	0.00233	0.704
1A	1	8	8	0.00221	0.00231	0.698
2	22.5	100	4.4	0.00219	0.00229	0.692
3	50	450	9	0.00221	0.00231	0.698
4	80	800	10	0.00221	0.00231	0.698
5	350	2,400	7	0.00259	0.00266	0.804
6	550	6,300	11	0.00300	0.00307	0.927
7	975	9,800	10	0.00385	0.00382	1.154

* Averages taken from Table 2.

** The values in this column have been adjusted for the finite boundary thickness at Station A.

*** C_{F_i} is computed from the Kármán-Schoenherr equation.

$$0.242/\sqrt{C_{F_i}} = \mathrm{Log}_{10}\,(R_{e_L}\,C_{F_i})$$

and C_F is the adjusted value.

$R_e/L = 3.0 \times 10^6$ per foot.

$R_e = 4.5 \times 10^6$ based on cylinder length (l).

$R_e = 4.9 \times 10^6$ based on total length $L = (l + \Delta l)$.

Pressure Measurements

All pressure measurements were made using Wallace and Tiernan Mercurial Precision Standards. For measurements in the tunnel, one standard was used as a differential manometer with part of the measuring system being pre-evacuated in order to reduce the time taken by the manometer system to reach an equilibrium.

Since the main object of the tests was to assess the effect of surface roughness on turbulent skin friction, it was necessary to ensure that the boundary layer over the cylinder was fully turbulent. In a preliminary study, it was found that the undisturbed boundary layer over the cone and part of the cylinder was laminar. It was therefore necessary to trip the boundary layer on the surface of the cone in order to obtain a turbulent boundary layer over the cylinder. A number of boundary layer trips were made up in the form of flat, sharp-edged washers, 0.030″ thick having a range of outside diameters. These trips fitted over the balance hold-down bolt and were held in place by part of the cone. The position of the trip on the model is shown in Figure 2.

Theory[9] and experiment[10] showed that the base pressure on a model was very sensitive to the type of boundary layer existing at the rear of the model. This characteristic of base pressure suggested a convenient method of confirming the type of boundary layer at the start of the cylinder. Figure 2 shows that the beginning of the cylinder and base of the cone are approximately in the same plane and a measurement of the cone base pressure would give an indication of the state of the boundary layer at that point. Using only the cone part of the model, a series of runs were made to determine the base pressure as a function of trip height above the cone surface. Figure 4 shows the results of these measurements. With no trip, the boundary layer at the

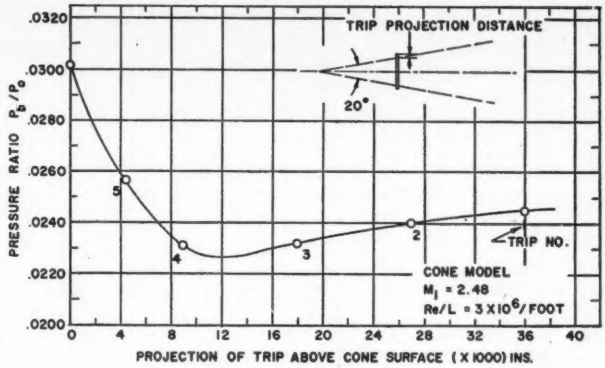
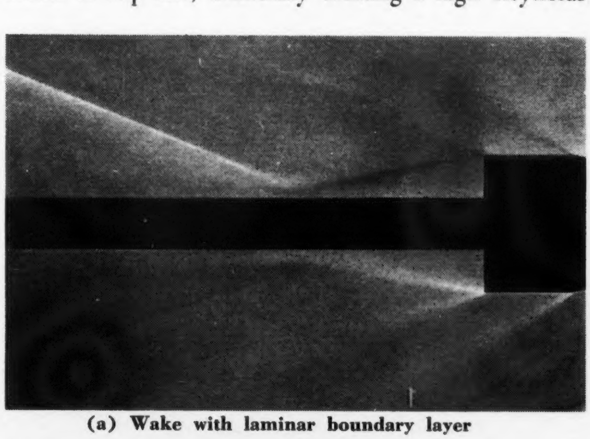


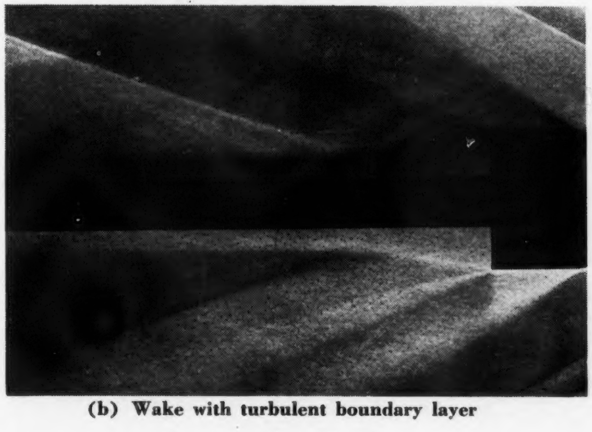
Figure 4

The base pressure on the cone model as a function of trip size

end of the model appears laminar and this condition results in a relatively high base pressure ratio (P_b/P_o)[10]. This evidence of a laminar boundary layer at the base of the model was supported by schlieren observations of the wake, which had a clear free boundary and a throat far from the base (see Figure 5a). The addition of one of the smallest trips to the model decreased the base pressure rapidly, the free boundary became fuzzy, and the throat of the wake moved forward towards the base of the cone as shown in Figure 5b. A further increase in trip size, artificially creating a high Reynolds



(a) Wake with laminar boundary layer



(b) Wake with turbulent boundary layer

Figure 5

Wake configuration with laminar and turbulent boundary layer on a cone-cylinder model at $M_1 = 2.48$

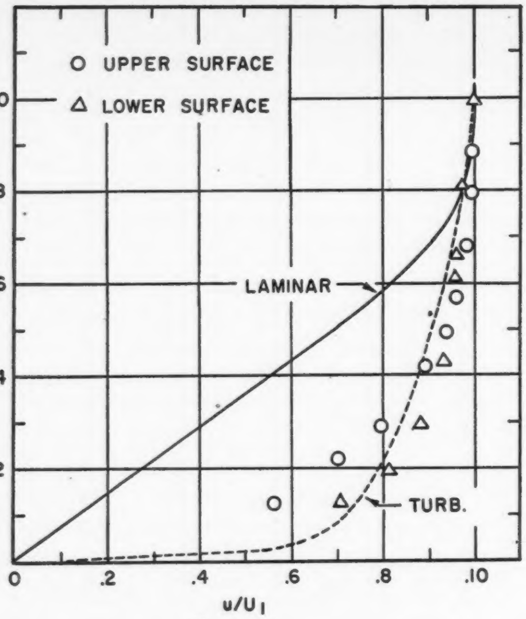


Figure 6

Comparison of the non-dimensional velocity profiles, taken at the beginning of the cylinder, with the theoretical laminar (Chapman and Rubensin) and turbulent (1/7 power law) velocity profiles. $M_1 = 2.48$, $R_e/L = 3 \times 10^6$/ft

number flow over the model, produced only a small change in base pressure and the wake configuration remained essentially unchanged. The results of this investigation showed that a sharp-edged projection of approximately 0.020″ on the surface of the cone was necessary to produce a turbulent boundary layer over the cylinder. A further increase in trip size only served to increase the boundary layer thickness over the model and to produce a larger momentum loss at the start of the cylinder.

Boundary Layer Measurements

A pitot traverse of the boundary layer was carried out at the start of the cylinder to verify the boundary layer profile and to measure the momentum thickness at that point. The traverse was repeated on the bottom of the model since it was known (Reference 6) that a slight misalignment with the flow can produce considerable change in the boundary layer development over the cone-cylinder model. Figure 6 shows how the non-dimensional velocity profiles compare with the theoretical laminar profile[11] and the 1/7 power law turbulent boundary layer profile. The boundary layer profile on the bottom surface of the model appears to have a fuller contour and to be about 10% thicker than the top boundary layer profile. This difference in boundary layer thickness shows that the model had a small negative angle of attack although considerable care was taken to position the model exactly on the tunnel centre line.

Skin Friction Coefficient

In order to provide a common basis for comparing the skin friction values obtained in these tests with those obtained in other investigations, the conditions should be met that the boundary layer (a) is turbulent and (b) at the start of the cylinder has zero thickness. The state of the boundary layer at the start of the cylinder was shown to be turbulent by a pitot traverse and by two flow visualization techniques, one optical, the other chemical, which are referred to in the main report.[5] However, the second condition is difficult to produce experimentally since, with the use of a trip, the effective origin of the turbulent boundary layer is some distance ahead of the beginning of the cylinder. An estimation of this distance was made[5] by extrapolating the momentum thickness, measured at the start of the cylinder, to zero. This is the method of correcting the measured values of C_F and R_e used by Chapman and Kester.[6] Very briefly, the procedure can be outlined as follows: one imagines the cylindrical surface of the model to be extended upstream a distance Δl, such that the turbulent boundary layer momentum thickness developed over this length matches the momentum thickness measured at the start of the cylinder. This consideration introduces an additional friction component Δf, computed from the momentum thickness, and increases the wetted area and Reynolds number by a factor Δl. With these corrections an adjusted average skin friction coefficient can be computed, as defined by Eq. (2), and a Reynolds number based on the length $L = (l + \Delta l)$.

$$C_F = \frac{f + \Delta f}{\frac{1}{2}\rho_1 U_1^2 \pi d (l + \Delta l)} \tag{2}$$

The increment of friction force Δf obtained from the momentum thickness was approximately 11% of the total skin friction force for the smoothest cylinder and 7% of the total skin friction force for the roughest model. The correction for the finite boundary layer thickness δ_A was made to all the results although it is probably a poor approximation for the cylinders with surface texture greater than the critical roughness, since the effect of roughness over the length Δl could not be estimated.

RESULTS AND DISCUSSION

The average skin friction coefficients for a turbulent boundary layer obtained on a cone-cylinder model are shown as a function of surface roughness in column 6 of Table 3. Figure 7 presents the results in a graphical form in which C_F is plotted against the average peak-to-valley height of the surface roughness. The critical surface roughness lies between 800 and 1,000 microinches. The flat portion of the curve gives a C_F value of 0.00231 for all surface roughness from 6 to 800

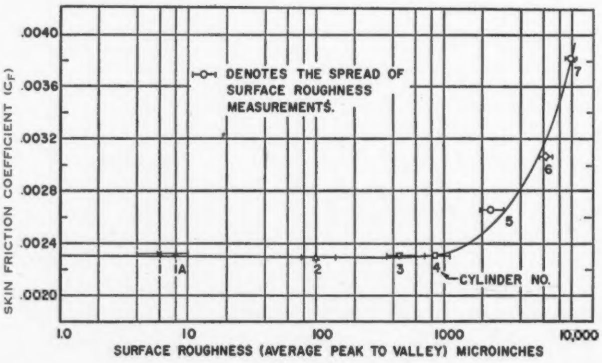


Figure 7

The turbulent skin friction on a cylinder as a function of the average peak-to-valley height of the surface roughness $M_1 = 2.48$, $R_e/L = 3 \times 10^6$/ft

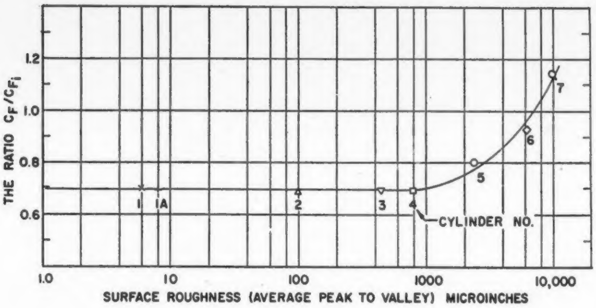


Figure 8

The effect of surface roughness on the ratio C_F/C_{F_i}. The value of C_F was obtained from force measurements on a cone-cylinder model. C_{F_i} was calculated using the Kármán-Schoenherr relation for incompressible flow.

$$M_1 = 2.48, R_e/L = 3 \times 10^6/\text{ft.}$$

microinches. This basic value of C_F is in good agreement with several theoretical analyses carried out for the skin friction coefficients on smooth surfaces.[12 13] The ratio of C_F/C_{F_i} (Table 3) for the smooth surfaces has an average value of 0.688, which is about 4% higher than the ratio C_F/C_{F_i} obtained experimentally by Chapman and Kester on a similar model at $M = 2.49$. The variation of C_F/C_{F_i} with the surface roughness K is shown in Figure 8.

In all the foregoing results, it has been tacitly implied that the present measurements on cylinders apply without adjustment to flat plates. However, the effect of lateral curvature on the local and average coefficients of friction is shown by Eckert[14] to be negligible for the ratio of boundary layer thickness to cylinder radius attained in these tests.

A comparison of the critical value of surface roughness obtained herein in supersonic flow with values obtained in incompressible flow can be made in two ways. The direct approach is to compare the value of K_c found experimentally with the results obtained by Prandtl and Schlichting from an analysis of Nikuradse's work. This was done, following the method used in Reference 4, by plotting the divergence Reynolds number for a series of values of the non-dimensional roughness parameter K/L; the divergence Reynolds number being taken as that value at which K/L departed from the turbulent skin friction smooth wall value. The resulting curve, shown in Figure 9, refers essentially to three-dimensional roughness in incompressible flow and illustrates how the admissible surface roughness K_{ad}/L varies as a function of the Reynolds number. In comparing the compressible flow result, the choice of the Reynolds number appears to be important. For this work the Reynolds number based on wall values was chosen. Using this parameter, and a total length of cylinder $(l + \Delta l)$, gave a value of K_{ad} about 1300 microinches. This value of K_{ad} is approximately 30% higher than the value of K_c found during these tests. The agreement is fair considering the errors associated with the measurement of surface roughness and uncertainties associated with the method of applying Nikuradse's results. It is also conjectural that the two-dimensional roughness offers more restriction to the flow than a three-dimensional projection (e.g., a sand grain) of the same height, due to the relief offered to the flow by a three-dimensional roughness element.

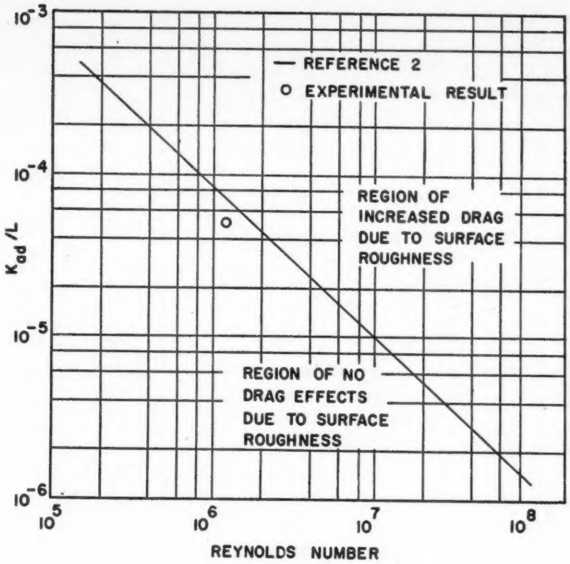


Figure 9

The allowable three-dimensional roughness as a function of the divergence Reynolds number for a flat plate in incompressible flow. The experimental point is a result of the work carried out using two-dimensional roughness on a cone-cylinder model in compressible flow.

A second approach to the critical value of surface roughness was made using the experimental observation of von Kármán[15], that the influence of roughness started when the height of the roughness had the same order of magnitude as the thickness of the laminar sublayer, or more specifically when

$$K_c = 3\nu/(\tau/\rho)^{1/2} = 3(\nu/U)(2/C_f)^{1/2} \qquad (3)$$

Accepting this value for K_c, determined from tests conducted in incompressible flow, calculations were carried out in Reference 5 which showed the critical height of the roughness to be about 900 microinches. This value of K_c, obtained by a completely different analysis, lies in the centre of the experimental critical roughness range.

The agreement between the compressible and incompressible flow results is good despite the fact that the character of the roughness (V-thread versus sand grains) is totally different for the two cases. One would suspect that measurements with still other types of surface roughness would show similar results; that is, the type, distribution and angular properties of the roughness apparently have very much less effect than the peak-to-valley height.

CONCLUSIONS

The rough cylinders exhibited no increase in skin friction over that of smooth cylinders for roughness peak-to-valley heights less than 800 to 1,000 microinches. Beyond this critical roughness, the skin friction increased rapidly with roughness height. This behaviour was in qualitative agreement with the results obtained by Nikuradse in incompressible flow.

The most significant measure of roughness was found

to be the peak-to-valley height of the projection and not the centre-line-average or root-mean-square height.

The average turbulent skin friction coefficients obtained on smooth cylinders agreed quite well with the results obtained by Chapman and Kester at the same Mach number using a similar type of model.

The present measurement is in agreement with the prediction advanced by von Kármán, in 1934, that the threshold height for surface roughness effects on skin friction was of the order of the thickness of the laminar sublayer. The experimental value of the critical roughness height (peak-to-valley) was found to be about one quarter the height of the laminar sublayer at the start of the cylinder.

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THE DEVELOPMENT OF ROLLS-ROYCE PROPELLER TURBINE ENGINES†

by D. P. Huddie*

Rolls-Royce Limited

THIS paper is an attempt to present the work done by Messrs. Rolls-Royce Limited on the development of Propeller Gas Turbine Engines for Aircraft Propulsion.

HISTORICAL

In 1943 it was realized that there were several advantages in a propeller turbine as a method of aircraft propulsion and the Company decided to carry out some experiments, including flight testing, on a simple propeller turbine engine. To save time it was decided to convert the current production jet engine (the Rolls-Royce Derwent) by fitting a suitable turbine and reduction gear. This engine was called the Trent. Flight testing of this combination commenced in 1945 with two of these engines installed in a Gloster Meteor, which was normally powered by two Derwent engines. This aircraft is shown in Figure 1.

The main purpose of this exercise was to obtain practical experience of the control problems of the propeller turbine combination at reasonable forward speeds and especially to investigate control system requirements for safe operation during take-off, approach and baulked landings.

Trent engines completed a total of 930 test hours, of which 300 were in flight. These experiments provided valuable information on propeller turbine control systems and the control system used on the Dart, which will be described later, stemmed directly from this work.

Also in 1943 the design of a twin-shaft propeller turbine engine was begun. This engine, which is shown in Figure 2, had a mass flow of 41.5 lb/sec at a compression ratio of 6 : 1. The low pressure compressor was a nine-stage axial and the high pressure compressor a single stage centrifugal. This engine completed about 3,300 bench and flight hours, but was dropped in 1949 owing to lack of a suitable aircraft. The engine developed approximately 4,000 hp with equivalent take-off specific fuel consumption of 0.710 lb/ehp/hr.

The Clyde was an ambitious engine for its time and, concurrently with the Clyde, the Company designed a small centrifugal compressor propeller gas turbine engine of 6 : 1 compression ratio. The engine was designed to give 1,000 hp and completed its first run in July 1946. This engine was subsequently named the Dart. A cross section is shown on Figure 3.

The Dart was originally designed to make the maximum use of the company's previous experience and, in fact, the original compressor was almost exactly the same as the supercharger of the last piston engine designed by the company.

Figure 1
Trent-Meteor

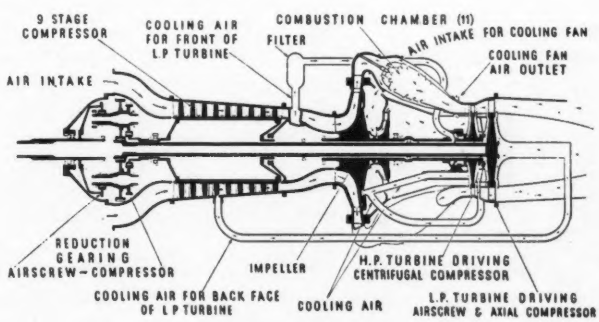


Figure 2
R.B. 39 Clyde

†Paper read at the Annual General Meeting of the C.A.I. in Montreal on the 3rd May, 1956.

*Chief Development Engineer, Civil Engines.

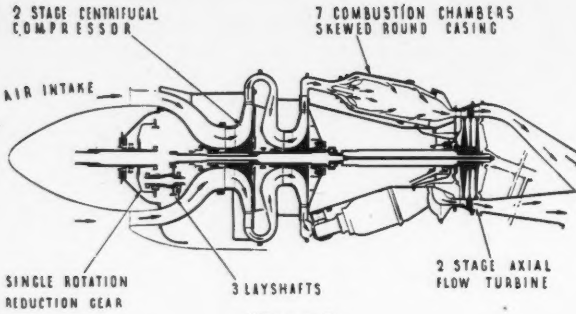


Figure 3
Dart

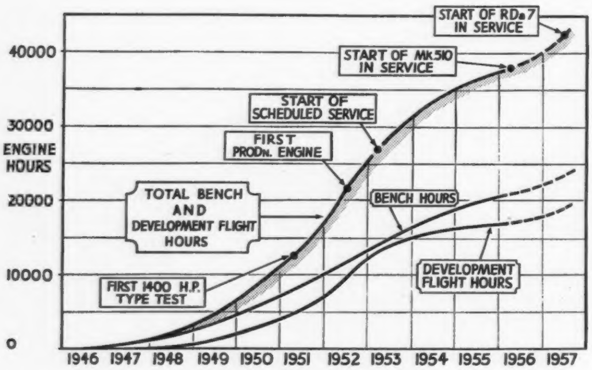


Figure 4
Dart engine development hours

The Dart was chosen to power the Vickers Viscount and, since it subsequently went into civil operation without any military experience, it is probably worth recording the development work carried out on the engine.

The engine completed its first type test at 1,000 hp in December 1948, but it was realized that, in order to make the Viscount into a commercially profitable aeroplane, more power was needed and the engine was redesigned in stages and developed up to the 1,400 take-off shaft hp with which we started production. The official production type test was completed in March 1951; the first production engine was delivered in June 1952; and scheduled service commenced in April 1953 after a total of 27,630 bench and flight hours, of which 13,100 were in flight. The build up of bench and flight development testing is shown on Figure 4.

The total cost of this development is shown in Figure 5 in pounds sterling. This includes the cost of manufacture of all experimental and prototype flight engines and of all bench and flight testing carried out by the Company plus normal factory overheads. It does not include the cost of flight testing in prototype Viscount aircraft. The main flight testing was performed in a Lancaster four-engined bomber, which had a Dart installed in the nose, and in three DC-3 aircraft, which were fitted with two Darts. The DC-3s had virtually a complete Viscount power plant.

The Lancaster shown in Figure 6 is fitted with a water spray-grid, which enabled us to carry out anti-icing tests in flight. This aircraft was also used to measure in-flight engine speeds and drags following control system failures. It will be readily appreciated that an aircraft with a centrally mounted test engine, and provided with full flying power independent of the test engine, is very suitable for this type of work.

One of the DC-3s was used by Rolls-Royce for general flight development and the other two were flown by British European Airways as freighters after a suitable Certificate of Airworthiness had been obtained. These two aircraft accumulated 3,870 engine flying hours and were extremely useful in early fault finding, in proving increased overhaul life to the satisfaction of the certifying authorities, and in giving to the first airline to use the Viscount preliminary experience in control and handling of the new power plant.

We were very satisfied with this method of engine development and propose to repeat the same exercise on the Tyne where we are using a four-engined Lincoln, with the Tyne installed in the nose, as our special flight test vehicle and twin-engined Ambassadors for normal flight testing and preliminary endurance flying.

Various design studies were continuously in progress for a power plant suitable for a successor to the Viscount as a short to medium range transport. These studies culminated in the Rolls-Royce Tyne, a 13 : 1 compression ratio, twin-shaft, axial engine of 4,000 shaft hp. This engine was designed to power the Vickers Vanguard, which is a somewhat larger aircraft than the Viscount, with the high cruising speed which is now universally demanded. The engine first ran in April 1955 and has already completed a 150 hour test to type test schedule at design flame temperature. The Tyne engine is shown on the same scale as the Dart on Figure 7.

The basic design of the Tyne engine is a good illustration of the use of the Company's development experience. The high pressure compressor and turbine are an actual scale of the corresponding components on the

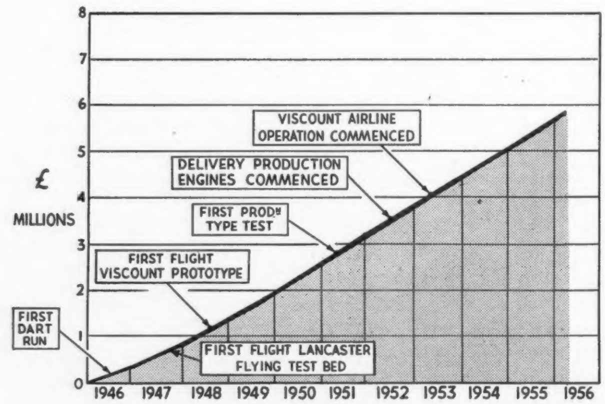


Figure 5
Dart development cost (cumulative)

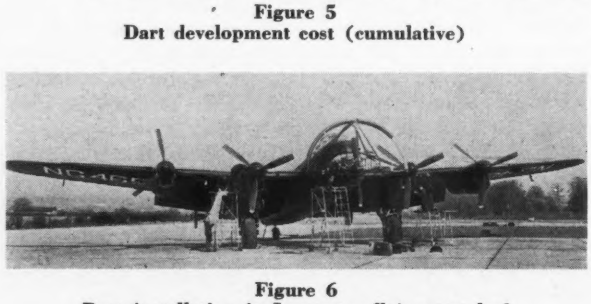
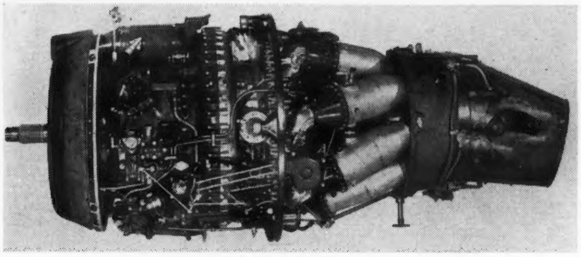
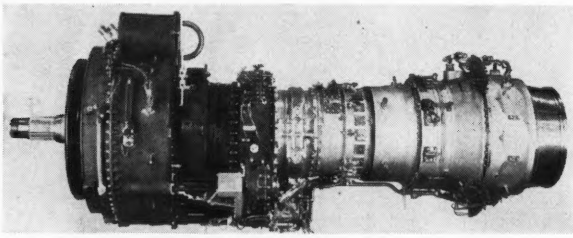


Figure 6
Dart installation in Lancaster flying test bed



Dart Engine



Tyne Engine

Figure 7
Dart and Tyne engines to the same scale

Conway engine. The low pressure compressor is also a scale, at a different ratio, of the Conway low pressure compressor and the three-stage low pressure turbine is based on the similar three-stage turbine used on the later Dart engines.

The turbine blade cooling used is just about to be incorporated in production Avon engines for military use and has been fitted to all Conway engines. It might be of interest to note that we have completed a total of over 5,200 engine hours on air-cooled turbine blades.

PERFORMANCE

It is interesting to trace the performance development of the Dart from the early production standard and to show the improvement which it has been possible to obtain since then. This is shown on Figure 8. The engine performance, up to and including the R.Da.7, is established by full engine running and the R.Da.8 performance is based on component rig testing, which has already been completed. It is interesting to compare the best performance in terms of cruise specific fuel consumption obtainable on the developed Dart with the performance of the first production Tyne engine. The

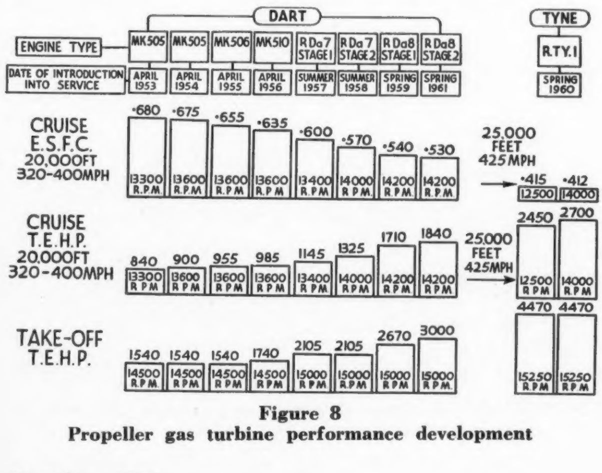


Figure 8
Propeller gas turbine performance development

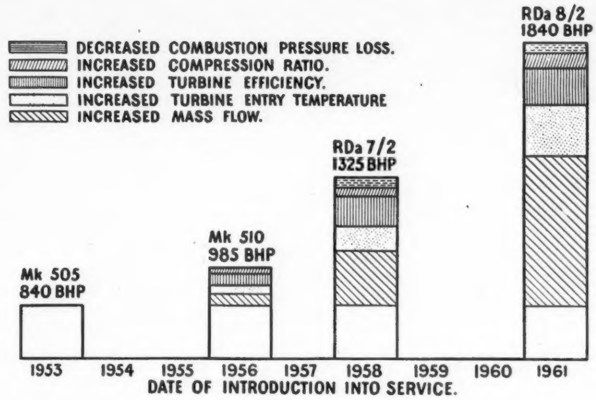


Figure 9
Dart performance development at cruise 20,000 ft

big improvement with the Tyne is, of course, largely due to the axial compressor with its higher compression ratio at reasonable efficiency.

We have attempted in Figure 9 to illustrate the means by which the performance improvement on the Dart has been obtained and Figure 9 takes three selected stages in the power development and shows how much of the improvement in cruise hp was obtained by:

Increased mass flow.
Increased turbine inlet temperature.
Increased turbine efficiency.
Increased compression ratio.
Decreased combustion pressure loss.

It should be emphasized that this Dart development has been achieved without any increase in the outside diameter of the engine, although slight increases in length have been necessary to accommodate a three-stage turbine in place of the original two stages; and to accommodate the strengthened reduction gears which have been required to handle the higher powers.

It can confidently be predicted that there will be considerable performance development on the Tyne by the classical methods of improved component efficiency, increased turbine inlet temperature and increased mass flow. I would, however, like to draw attention to a point clearly made in Mr. Lombard's paper on "Low Consumption Gas Turbines," delivered before the joint S.A.E. and Royal Aeronautical Society conference last year. This was that, as distinct from jet engines, the propeller turbine engine continues to improve its efficiency with increasing compression ratio and increasing turbine inlet temperature. We are confident that the basic twin-shaft axial compressor formula with air-cooling of the early turbine stages is for this reason an engine which is capable of a lot of performance development.

The pressure on propeller turbine development has been towards higher cruise powers to achieve the highest possible cruising speed. As a Company, we are still convinced that about 450 mph represents the useful upper limit of propeller aircraft cruising speed. A comparative study of modern propeller turbine engines and by-pass engines showed no economic advantage for the propeller turbine engine above this speed.

The economic case for the propeller turbine engined aircraft for short to medium ranges at 450 mph rests

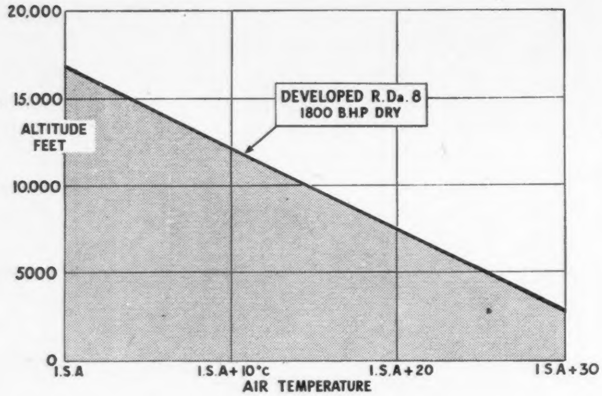


Figure 10
Altitude air temperature envelope within which stated take-off power is available

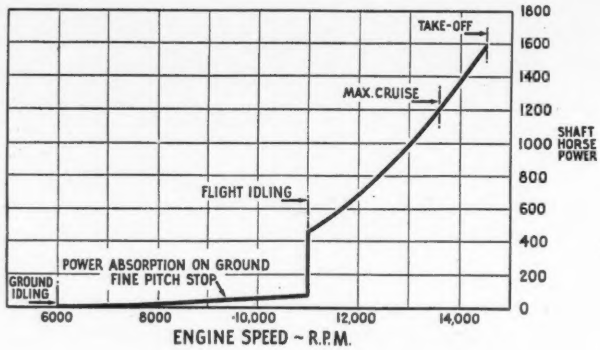


Figure 12
Interconnection of Dart Mk 510

solely on the inherently greater flexibility of this power plant. The fuel penalty for cruising at other than optimum altitude is less than with the jet engines, as is also the fuel penalty for prolonged stacking.

As we see it, one of the great difficulties of really high speed propeller turbine aircraft is propeller noise, which is dealt with later in a separate section.

All Dart engines have been equipped with water methanol injection for power restoration on hot days and the engine delivers full I.S.A. power up to I.S.A. +30°C. A similar system for water methanol injection will be developed on the Tyne so that it will be available if required.

If we consider the last stage in development shown for the Dart, the development to high cruise powers has made available a take-off power at I.S.A. sea level which is much better than can be used in the Viscount. Figure 10 shows the altitude and temperature envelope inside which the required take-off power will be available. It can be seen from Figure 10 that for normal use there is not likely to be a case for power restoration by water methanol injection on this engine.

CONTROL SYSTEM

Figure 11 shows diagrammatically the basic control system as used on Rolls-Royce propeller turbine engines. It can be seen that the engine throttle lever and the propeller speed control lever are mechanically interconnected; and this interconnection is made to give the desired relationship of engine speed and turbine inlet temperature (or power) over the speed range. The mechanical interconnection shown above will only maintain the desired relationship between speed and turbine inlet temperature for one ambient air temperature and aircraft speed and, therefore, it is necessary to vary the geometry of the interconnection. This is achieved as shown by Figure 11. To ensure optimum specific fuel consumption, it is necessary with a propeller turbine engine to run at the maximum permitted turbine inlet temperature. This adjustment can be performed, either manually by the pilot through an electric actuator, or automatically by a temperature control using an amplified thermocouple signal and the same actuator. So far all Dart operation has used manual control of turbine inlet temperature by the pilot, although considerable development work has been done on the automatic system. We deliberately chose the mechanical interconnection with manual trimming as a starting point because of its inherent simplicity.

Figure 12 shows the basic interconnection curve for a Dart Mk 510 engine. It will be seen that, at the minimum control rpm of the propeller control unit, the fuel flow can be progressively reduced without further reduction in speed.

On a fixed shaft engine like the Dart, the maintenance of a relatively high engine speed with low fuel flow enables a considerable drag to be available without putting the propeller into reverse pitch. Figure 13 shows the pro-

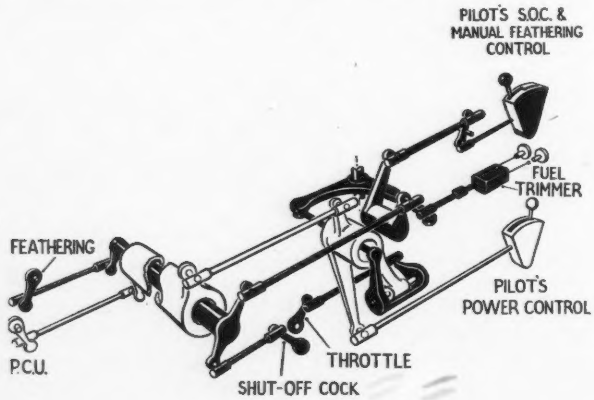


Figure 11
Dart—interconnected controls with variable datum throttle linkage

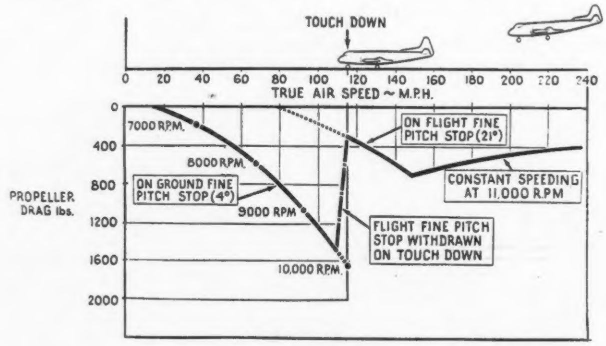


Figure 13
Dart Mk 506 engine approach and landing drags with throttle shut

peller drag available during a normal approach. Until the aircraft's wheels are on the ground, the propeller is maintained on the flight fine pitch stop which is set at 21°. On touching down, the flight fine pitch stops are withdrawn and the propeller allowed to go to much finer pitch with the provision of considerable drag. This is shown in Figure 13.

It can be seen from Figure 13 that, on the flight fine pitch stop, there is drag available on the Dart during the descent. We have arranged the basic interconnection of the Tyne engine to be similar to the Dart so that some propeller drag is available during the descent. On touch-down with the Tyne, the drag available on going through to the ground fine pitch stop is not sufficient to take the place of a reversing propeller, since the propeller is only driving the low pressure shaft system and not the whole engine. It is, therefore, necessary to provide a fully reversing propeller on this engine.

One special feature that we have included on the Tyne engine controls is worthy of mention. For approach conditions, it is desirable to have a relatively high propeller speed to ensure a rapid acceleration to full forward thrust in the case of a baulked landing. This means a relatively high, low-pressure system speed and we have provisionally chosen 11,500 rpm which is 75% of take-off speed. It is also necessary for approach to run at minimum fuel flow to give the propeller drag conditions mentioned above for the normal approach. The resulting combination of high, low-pressure compressor speed and low, high-pressure compressor speed is obviously one in which the low-pressure compressor would tend to surge. We have, therefore, fitted a bleed valve between the two compressors, which is controlled automatically by corrected speed signals from the two compressor shafts, to enable us to achieve the engine conditions desirable for descent and approach with the high, low-pressure system speed to ensure rapid acceleration in the event of a wave-off.

At take-off, the high drag of a failed engine makes it imperative to have automatic propeller pitch coarsening. On our engines, this is achieved by a low torque switch through a circuit which is armed for take-off. This ensures that the propeller is automatically coarsened to feather when the torque falls below a pre-determined

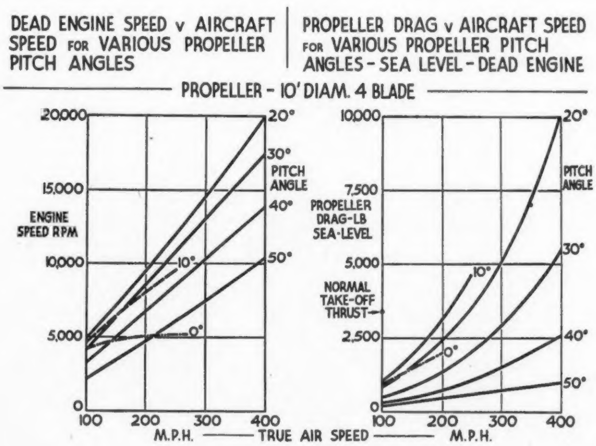


Figure 14
Engine - Dart Mk 510

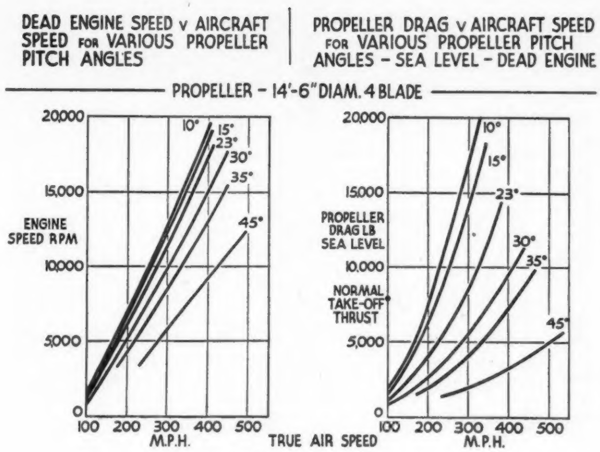


Figure 15
Engine - Tyne

level. This requirement is well known and we need not spend any further time on it.

To illustrate the other requirements, we show propeller drag and engine speed plotted against aircraft forward speed for the latest production Dart in the Viscount in Figure 14. We have been able to demonstrate that the engine can stand without failure the maximum engine speed that would be achieved and the aircraft can stand the maximum drag.

Figure 15 shows the engine speeds and drags plotted against aircraft forward speed for the Tyne engine. In the case of the Tyne, the aircraft forward speed is driving through the propeller; not the whole engine, as in the case of the Dart, but only the low pressure shaft system. The net result is that, at the same propeller pitch, much higher engine speeds would be reached, so precautions have to be taken to control this speed down to an acceptable level. It can be seen from both sets of curves that the essential requirement, to control both maximum engine speed and maximum drag, is to maintain a high propeller pitch and this becomes more necessary with increasing aircraft forward speed. The method by which this high propeller pitch is ensured in flight will, no doubt, vary, but the essential requirement is that for a given engine/propeller combination and at the maximum true air-speeds that will be encountered, provision must be made to ensure that the propeller pitch can never fall below a safe figure in flight.

The speeds and drags for these failure cases can be calculated once the characteristics of the engine components and the propeller are known. However, the importance of the critical failure cases are such that actual confirmation of the calculations is desirable and this is one of the uses for the four-engined flight test vehicle mentioned earlier, since the failures can be simulated in flight, the engine speeds recorded and propeller drag deduced from the aircraft performance. To enable actual measurements of windmilling powers and speeds to be made, we have built a test bed shown in Figure 16.

This figure shows a Dart mounted on this test bed and, for convenience, we have used a piston engine to provide the drive. This facility enables accurate measurement of engine motoring powers to be carried out. This

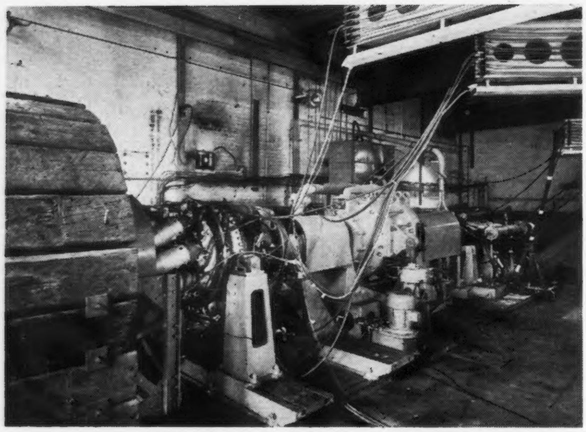


Figure 16
Dart motoring test bed

test stand also enables us to carry out endurance running at conditions which are not easy to produce on the normal test stand, i.e. with the propeller driving the engine.

SERVICEABILITY

An earlier section has indicated the test hours run and money spent on the Dart to provide a civil engine without a military background. We will now examine very briefly the behaviour of this engine in civil operation. Figure 17 shows unscheduled engine removals per thousand engine flying hours on a three-monthly average since the start of Dart operation. Over the total operation so far, the unscheduled engine removal rate averages 0.288 engine removals per thousand engine flying hours and the average for all operators over the year 1955 was 0.182.

The first and second peaks in the curve were due to different reasons. The early peak was due to troubles which showed up in service but had never been found in development. Fortunately, these were of a minor nature and did not prove difficult to cure. The second peak was due to relatively long life troubles. Both peaks contain a number of removals which might be ascribed to ignorance of the engine, i.e. engines removed because of an unusual symptom where subsequent strip and inspection showed the removal to be unnecessary.

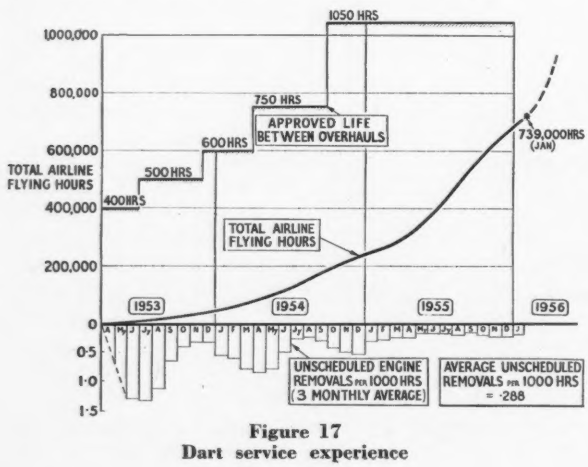


Figure 17
Dart service experience

There are two features about our service experience on the Dart which I think are worthy of mention. We have had fatigue failures in service, both of the high pressure turbine blade and of the first stage compressor rotor. Both of these failures were subsequently established as being due to resonance at an engine speed between ground and flight idling, i.e. in the taxiing range. These resonance failures had never occurred in development, although some of the components that failed had been tested to well beyond the hours at which failure occurred. Inevitably a high proportion of the endurance running on development is done to the official type test schedule. One of the merits we claim for the British type test schedule is that it does a fairly thorough search of the engine speed range between maximum continuous conditions and flight idling.

We all do our best by various technical tests to identify resonances and make the changes necessary to cure them, but experience shows that it is a wise precaution to do the maximum amount of endurance testing so that the failures, which have not been found by special testing, can happen during the testing stage of the engine and not in service. I think we would all agree that, once a fatigue failure has occurred in an engine component, modern strain gauging techniques usually allow the cause of the failure to be identified. I can claim that no fatigue failure has yet occurred in the Dart of which we have not been able to identify the cause and effect a cure once the failure has happened.

The fact that the two types of failure, which occurred in service, were due to resonances between ground and flight idling and that the present type test schedule calls for virtually no running between these speeds, seems to indicate that the current British practice of searching the speed range from maximum continuous to flight idling during the type test should be extended to search the complete speed range from maximum continuous down to ground idling. We are currently performing trial tests with a tentative schedule designed to meet this requirement. Great care is normally taken to ensure that, during the development period, some components reach a high life and, since a lot of this running is bound to be at type test conditions, it is felt that the type test

Figure 18
Dart standard flame tube after 750 hrs service life

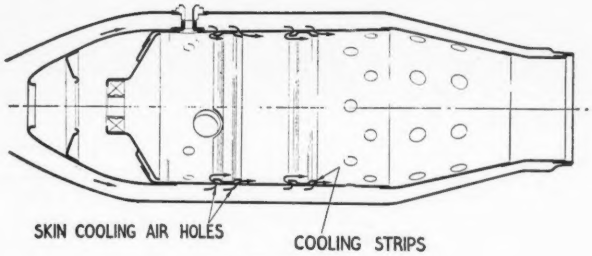


Figure 19
Dart skin-cooled flame tube

should cover some running at all engine speeds which can be used in service, including taxiing.

FLAME TUBES

As an illustration of mechanical development, I would like to examine briefly the development of the first life-limiting component we encountered in service on the Dart. This was the flame tube or combustion liner.

Figure 18 shows the condition of the original Dart flame tubes after 750 hours service life. It can be seen that these flame tubes show heavy buckling forward of the shoulder hole with cracking of the shoulder hole itself. The reason for this will be fairly obvious when we look at the wall temperatures of the flame tube.

We decided to try skin-cooling of the flame tube by a method suggested by Dr. J. S. Clarke of Messrs. Joseph Lucas Ltd. This method is shown in principle in Figure 19. The cooling rings are attached to the flame tube and cooling air enters both up and downstream of these rings through the small holes shown. The effect on skin temperature can be seen in Figure 20. The original flame tube has very high temperatures upstream of the shoulder hole cooling device and comparatively low temperatures downstream of it. This means that the hot metal upstream is rigidly restrained by the cool and stiff shoulder. On the new tube it can be seen that not only are the skin temperatures much lower but there is no significant temperature gradient across the cooling device.

The result in service is shown in Figure 21, which shows the condition of an engine set of the new tubes after just over 1,230 hours in service. The condition of these tubes was such that they were returned to service for a further 500 hours. We are fairly certain, from the results of what has now been an extended service

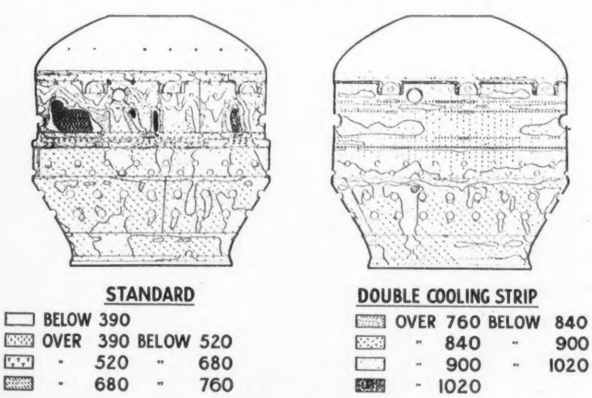


Figure 20
Development of Dart flame tube
Skin temperatures - °C

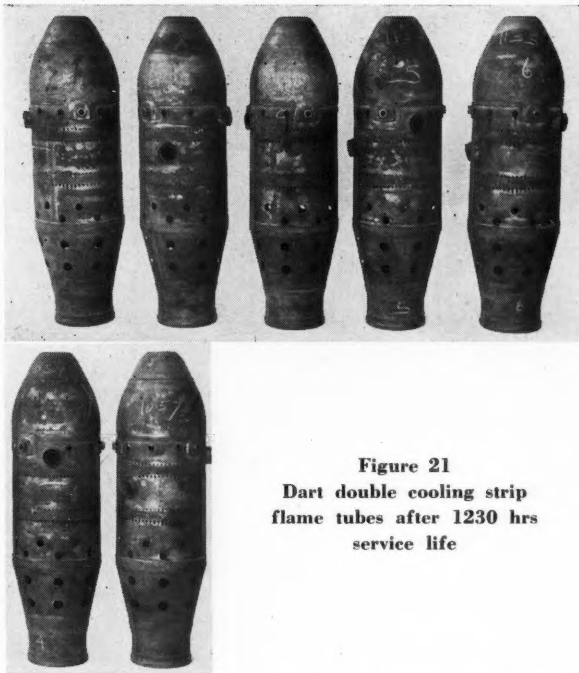


Figure 21
Dart double cooling strip flame tubes after 1230 hrs service life

trial, that the new tubes will be good for between 1,500 and 2,000 service hours without attention.

The cooling strip, as shown, has the basic disadvantage that it does not pick up the total head of the cooling air, but only the static pressure. It will therefore become less effective as combustion pressure loss is progressively reduced. The device has been so successful, however, that we are now carrying out experiments by expanding the diameter of the flame tube in the region of the cooling strip to enable the cooling holes to pick up as much of the total pressure as possible.

NOISE

This section on propeller noise must necessarily be brief, since it is part of a general paper, but I thought it worth including since it affects considerably the design and use of propeller turbine engines, especially at relatively high aircraft forward speeds.

Some years ago, in conjunction with Messrs. Vickers-Armstrongs Limited, we carried out a fairly extensive series of tests in the Viscount to determine the effect of various factors which could affect propeller noise. We set out to vary three factors independently, i.e. propeller power or disc loading, propeller rotational speed and aircraft forward speed. We found that propeller disc loading has a small effect on noise, but that by far the greatest effect was the true helical tip Mach number of the propeller blade. Figure 22 shows the total noise in the frequency band between 75 and 300 cps plotted against propeller helical tip Mach number. This noise was recorded in the cabin of the plane of the inboard propellers. The points shown are the actual observations at various propeller rotational speeds and aircraft forward speeds, and substantially the same Mach numbers have been, in all cases, achieved by at least three different combinations of propeller rotational speed and aircraft forward speed. It can be readily seen that it would have been easy to draw a steeper line through the

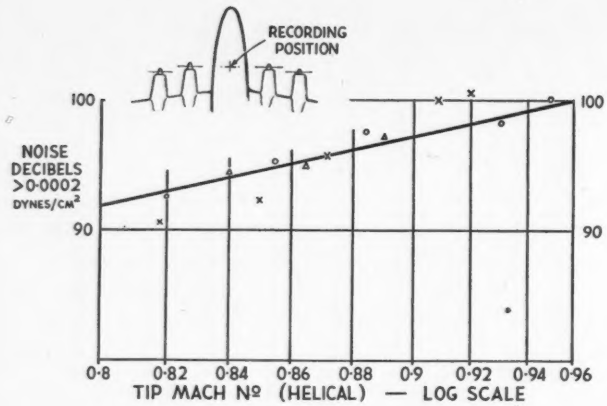


Figure 22
Vickers Viscount propeller noise

observed points but, with the line as drawn, the noise as energy varies as the 10th power of the helical tip Mach number.

The results shown are only for the station in the plane of the inboard propellers, but similar conclusions can be drawn from the results at several stations towards the front of the aircraft.

As a result of these tests, we reached the conclusion that, in order to maintain the Viscount's noise level in the Vanguard, the cruise helical tip Mach number on the Tyne would have to be restricted to 0.85. The attempt to limit propeller noise by this means inevitably leads to something of a compromise in design, since the highest propeller rotational speed is required to give the maximum take-off thrust and, at a given forward speed in cruise, the propeller helical tip Mach number can only be limited by limiting the rotational speed. Thus, there is an incentive to provide the greatest possible difference between take-off and cruise propeller speeds and then select a reduction gear ratio to satisfy the conflicting requirements of take-off propeller thrust and cruise noise.

Because of the importance of this factor to the future operation of propeller turbine engines and because of the fact that the proposals for propeller turbine aircraft in other quarters would seem to be at variance with the conclusions we have reached from our noise tests, we have just concluded, in conjunction with Messrs. Vickers-Armstrongs Limited, a very extensive series of tests on the Viscount aircraft in which we covered a wide range of propeller rotational speed and aircraft forward speed. We think we have tested the range of these variables which will cover proposed propeller turbine operations for some time to come. The experiments included the synchronization and synchro-phasing of propellers. Unfortunately, the results have not been analyzed at the time of writing this paper, but should be available at the time of its delivery. We feel, however, that this subject is important enough to be worthy of a paper on its own in the near future.

I would like to thank Messrs. Rolls-Royce Ltd. for permission to publish this paper and the various members of the Rolls-Royce staff who helped to prepare it.

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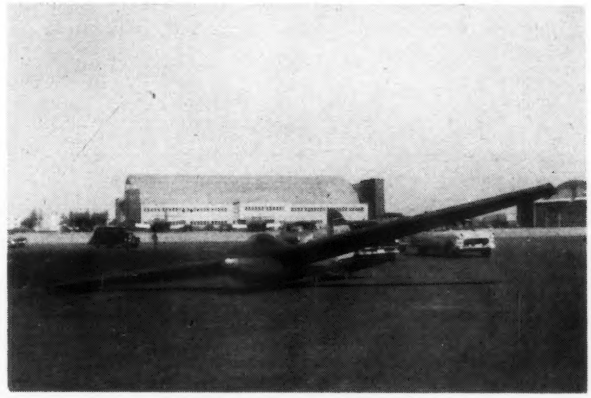
TECHNICAL FORUM

RECORD SOARING FLIGHT IN CANADA†

by S/L A. W. Riddell, R.C.A.F.

The following account describes a flight by S/L A. W. Riddell from Pincher Creek, Alta., on June 26, 1956, during an informal soaring meet there. Subject to confirmation by the Soaring Association, the flight set a new official absolute altitude record of 17,570 ft and an unofficial record of 20,200 ft. The flight was made in a single-place sailplane, the Schweizer 1-26, built last winter from the kit by S/L Riddell. Incidentally, it appears to be also a record altitude for the 1-26, of which about 25 examples are now flying. The flight earned Bill Riddell the fourth Canadian Gold C Height leg.

C. B. Jeffery



S/L Riddell's Schweizer 1-26

On the 26th June, the general weather pattern had changed from the previous day, where downwind thermal streets prevailed, to streeted convective cloud which appeared to be imbedded in a wave, being across the wind which was 30 to 35 mph on the ground. The system was parallel to the Livingstone Range of the Rocky Mountains which put up a primary wave about 5 to 6 miles downwind, a secondary wave about 5 to 6 miles back and a third over the Porcupine Hills another 5 to 6 miles back. It appeared that other waves may have been further back but were not explored. The system extended north 20 to 30 miles and south to the Crows Nest Pass when it started up but by evening the wave extended from the horizon to horizon with a different plan form. Early in the day, convective cloud only was forming in the up wave face and dissipating down wave. Due to the N-S run of the Rockies, the sun was heating the ground all afternoon just ahead of each wave, causing the convective cloud to street across wind by rising into the wave. I consider this requires more study as it would tend to create a stable local condition and help trigger off waves. This cloud was generally based at 12,000 and topped at 16,000. The maximum lift was ½ to 1 mile in front of the cloud face. From 1600 hrs on, this convective cloud gradually dissipated leaving a clear sky with extremely smooth wave lift. From 1800 hrs on, the first lenticulars formed on the primary wave and developed along the wave until at 1900 to 2000 hrs they were horizon to horizon continuous. I estimate they were based above 30,000 when they formed and seemed to deepen to 20,000 by 2000 hrs as the wave filled in. This, of course, was a picture setting for the sun going down behind the Rockies.

The flight itself was quite eventful. Take off was at 1402 hrs from Cook's air strip at 3500 asl; released at 1419 at 6500 indicated altitude in the wave, in front of the embedded convective cloud. I had made a previous flight at 1316 hrs and released under the cloud, which was a mistake that I was able to correct on the next flight. The lift was very definite over a broad area upwind of the cloud. At 1428 I was at 9,500 ft. At 1440 I was 12,000 ft at cloud base and a mile upwind or ahead of the cloud. At this point, I pushed forward to the down area between the primary and secondary wave to locate an escape area for, at this time, I did not know the wave went above the cloud. I, of course, had started in the secondary wave to climb up as the primary wave was over very rough foothills country. Having established the trough, I then felt comfortable about exploring this wave condition. I flew back into the secondary wave at 1450 and started to climb in from the cloud face well in front; at 1510 I was at 15,500 in front and above the cloud top. I continued to explore this secondary wave above cloud and it appeared to top out at 18,000. I then pushed forward into the primary wave and only lost some 3,000 ft in so doing. This rather surprised me as I had expected to lose 5 to 8,000. By 1620 I was back to 18,000 and at 1631 I topped 20,000 and turned back for a down current. From this position, I was looking down on the Rocky Mountains and could see up the Crows Nest Pass as far as Natal, where the pass turns south. I had forgotten my movie camera but couldn't kick myself with the harness done up.

The usual conditions prevailed at take off and consequently my barograph had not been turned on until I was in flight; I suspected it had stopped around 18,000 ft (confirmed later), so I needed a low point for Gold C gain. The lift at 20,000 was very good but without oxygen I only stayed to see the needle pass the mark and then I turned back to the interwave down area. I spent 25 min going down, sampling the lift at intervals to position myself for the climb back. At 1659

†Received 13th August, 1956.

hrs I was down to 6,600 ft indicated and about 2,000 ft above ground over a ridge. I felt this was low enough and started the climb back. I had crossed from the primary to the secondary wave to go down because of the terrain and was on the secondary wave. I got back to 15,500 by 1715 and, as I topped the lift I was in, I pushed upwind to the primary wave. Again I lost only 3,500 ft and arrived at 1724 at 12,000. I was back to 16,000 at 1735 and at 1800 I was at 17,500. I found a better part of the wave and at 1805 passed 20,000 and then turned for home. I had been long enough above 15,000 ft. As I turned for home, I tapped the altimeter and it indicated 20,200 before I got into the down area. Full spoiler 90 asi and about 1,000 fpm down, I crossed where the secondary wave should have been but it was dying and no lift resulted. I could see the high lenticulars forming; they were intriguing but I was too cold. Summer clothes are not good enough. I never lost so much altitude in so short a time in a glider but I had to get down to a reasonable level for I know the effects of anoxia.

I landed at 1830 and was almost too chilled to stand up. The first thing done was to have Al Foster open the barograph. The trace was good and although it is only a 4,800 meter graph, the trace went to the top and tracked horizontally until I came down to around 18,000, where it joined me again on the way down. However, there is enough climb on the trace to give me a good margin for the Gold C leg. A most successful flight and it vindicates my faith in the Rocky Wave.

LETTERS TO THE SECRETARY

ON TITLES

A title may generally be expected to add to a man's pride and prestige. It seems unfortunate and unnecessary that the use of one that is of a controversial nature has been adopted for those who are directly responsible for the safety of civil aircraft.

The title of "mechanic" has been known and respected ever since mechanisms were introduced to assist the bodily power of man. An aero engine mechanic or an aircraft mechanic is separated by his title into a special category, of which he is rightly proud, and a master mechanic is to others what a Master of Engineering is to an ordinary graduate engineer, if not more.

The title of "engineer" on the other hand, is claimed, rightly or wrongly, by the Professional Engineer. Even at best, it is somewhat ambiguous and is often qualified by being written "aeronautical engineer" etc. To refer to a qualified mechanic as an "air engineer" inevitably introduces an element of confusion. It also leads to the adoption of such titles as "Chief Engineer" by those who have no professional qualifications. This reflects badly both on the man who could call himself "Chief, Director, or Superintendent of Maintenance" and also on those whose position is equivalent to that of the "Chief Engineer" of other organizations, which requires full professional status.

It is appreciated that there are obstacles and may be prejudice against the abandoning of the title "air engineer". No easy solution is apparent or offered and the opinions expressed are personal and should not be interpreted as reflecting in any way the views of the writer's employer. It is suggested, however, that there are advantages in a change, which would warrant further consideration.

Montreal — C. H. Skelton

THE BIRTH AND EVOLUTION OF THE GAS TURBINE

The article by V. E. Crompton of Orenda Engines Limited in the September issue of the Journal has been brought to my attention. The paper gives a reasonably concise historical record of the development of the gas turbine in all countries except Canada. It makes no reference to the work done by the Canadian firm of which Orenda Engines is the lineal descendant.

Turbo Research Limited was organized under letters patent 7 July, 1944, to carry on research and development work which had been proceeding since 1943 under the National Research Council.

One of the terms of reference of the Company, adopted at a meeting on 23 February, 1945, was to design, construct and develop prototype units, and on 21 March, 1943, two alternative turbine designs, which had been prepared by the engineering staff, were considered in detail by the Technical Advisory Committee. The Committee recommended to the Board of Directors that Turbo Research Limited should concentrate on the development of the axial unit, i.e. TR2, having an 8-stage compressor. This was the decision that resulted in the design and construction of the Chinook (TR3), of which three were constructed, I believe, after Turbo Research Limited was dissolved in 1946 and its function taken over by A. V. Roe Canada Limited.

Ottawa — J. H. Parkin

C.A.I. LOG

SECRETARY'S LETTER

EDUCATION AND TRAINING

LAST January I reported briefly on the steps which the Institute was taking in connection with Education and Training. A good deal has happened since then and it is time I brought you up to date.

The work of the Education and Training Committee of 1955-56 was reviewed by its Chairman, Professor T. R. Loudon, in his Report to the Annual General Meeting in May. This Report was subsequently published in the June issue of the Journal. In referring to the Questionnaire which had been sent out to some 80 employers of technical manpower, Professor Loudon said that, although the returns had not yet been fully analyzed, it was evident from a preliminary study that there was a fairly general demand for more training at the Technical Institute level.

This finding has been confirmed by the detailed summary of the returns, which has now been completed by the Department of Labour. There seems to be a more serious shortage of Technologists – that is, of design-draftsmen, laboratory technicians, engineering assistants, process planners and the like – than there is of professional engineers or skilled craftsmen. Accordingly the Institute has chosen, as its first task, to tackle this problem of the Technologist. It must try to increase and improve training facilities, to establish a standard of Technologist Diploma courses across the country and, above all, to attract boys into the field.

Now that its objective has been defined, the Council has changed the Committee structure and, in place of the central Committee which carried out the initial reconnaissance, six Provincial Committees are being set up, in British Columbia, Alberta, Manitoba, Ontario, Quebec and Nova Scotia. These Committees will report directly to the Council and Mr. R. B. McIntyre has been appointed as the Councillor principally responsible for guiding and coordinating their efforts. The names of the members of these Committees will appear in the List of Members (to be published shortly). Any members of the Institute interested in this work – and who should not be? – should get in touch with their Provincial Committees; I am sure that their help will be most welcome.

INTERNATIONAL MEETING

We are trying to arrange reduced travel rates on the airlines for those of our members who will be attending the International Meeting at the end of November. If we are successful, details of the necessary procedure will be enclosed with the Meeting Notices when these are distributed.

I hope that the plan, which will apply not only to our members but to their families as well, will make it easier for people to attend, particularly from the more distant Branches. And, speaking of families, please remember that ladies will be very welcome. A special programme is being arranged to entertain them while the technical sessions are in progress and, of course, we hope to see them in force at the dinner.

MONTREAL

Once again the Montreal Branch started their season with a Golf Tournament. I managed to arrive in time to witness its closing stages and to enjoy the party afterwards. There is a great deal to be said for a "meeting" of this sort right at the beginning of the season; it is held at the end of August and so does not interfere with the normal series of technical meetings and it certainly provides a very effective means of "warming up". I can recommend it to other Branches – with my usual austere proviso that social events should never be allowed to intrude upon our technical programmes.

BRANCHES

NEWS

Montreal—

Reported by W/C C. R. Thompson

Golf Tournament

The Third Annual Golf Tournament, sponsored by the Montreal Branch, was held at the St. Andrews Golf & Country Club, St. Andrews E., Quebec, on the 24th August. The tournament, under the co-chairmanship of Ray Conrath and Johnny Chadburn, continued the high standard which we have come to expect of these annual affairs.

The rains earlier in the day cleared off nicely and over 100 members and guests enjoyed a good time of golf and fellowship. Members from other Branches came from as far away as Mont-Apica, Quebec and Toronto, as well as a good representation from Ottawa. The head table at the banquet following was graced by G/C R. M. Aldwinckle, G/C R. McMillan, our genial Secretary, Charles Luttman, and members of the Montreal Branch executive.

The prize winners in the tournament were as follows:

Members

Bob Wright Memorial Trophy	D. F. MacLaren
Low Net	E. C. V. Norsworthy
2nd Low Gross	G/C R. McMillan
2nd Low Net	T. A. Harvie
3rd Low Gross	A. Nicholls
3rd Low Net	H. L. McKeown
4th Low Gross	W/C R. A. Skuce
4th Low Net	A. Schropfer
5th Low Gross	E. B. Schaefer
5th Low Net	A. E. Larratt
6th Low Gross	R. L. Hanson
6th Low Net	G. J. Stringer
7th Low Gross	W/C E. P. Bridgland
7th Low Net	J. Schaffer
8th Low Gross	J. R. Holding

Guests

Ross Aero Trophy	F/O J. Martin
1st Low Net	R. G. Stoddart
2nd Low Gross	W. Chester
2nd Low Net	S/L C. F. Sandford
3rd Low Gross	F/L M. Friedl
3rd Low Net	W. Whiteford
4th Low Gross	C. Saylor
4th Low Net	A. Forker
5th Low Gross	S/L E. J. Trotter
5th Low Net	Lou Chow
6th Low Net	F/L P. St. Louis

Hidden Hole Prizes

One Low	J. Woodridge
Three Low	R. A. Neale
Two High	J. J. Waller
Four High	D. B. Bates
Five High	H. Scheunert
Seven Low	L. K. Rutledge
Nine High	H. H. Whiteman
Nine Low	W. McKenzie
High Gross	W. R. Cuff

Attendance prizes were won by F/L J. W. Garland, H. A. Ross, S. M. Weir, D. Donald and J. P. Donnelly.

Toronto—Reported by W. T. Heaslip

September Meeting

The first meeting of the current season was held in the DeHavilland Cafeteria on Wednesday, September 12th.

Mr. F. H. Keast, Chairman of the Branch, after welcoming the members and their guests to the new season of Branch activities, introduced the Chairmen of the various committees and outlined the changes in the meeting arrangements for the year. He reviewed the considerations leading to the selection of the DeHavilland Cafeteria as a meeting place, pointing out that this locale offered the satisfactory combination of a suitable auditorium, adequate parking and congenial atmosphere. The provision of a bar, he noted, should add considerably to the comfort and inclination to continue with informal after-meeting discussion.

The Chairman then introduced the speaker of the evening, Mr. J. W. Ames, Chief Test Engineer (Structural and Mechanical) of Avro Aircraft Ltd.

Mr. Ames spoke on the international gliding in which he participated this summer at Saint Yan, France. He titled his talk "Report to the C.A.I. on the World Gliding Championships", in recognition of the considerable financial support given to the Canadian team by the Sustaining Members of the C.A.I.

Pictures of all the types of sailplanes in the competition were also presented which, along with remarks on their performance capabilities, equipment and excellence of workmanship, clearly pointed out the seriousness with which the competitors enter this competition. In spite of the high degree of refinement of some of the sailplanes, Mr. Ames emphasized that the skill of the pilot was still the most important factor. As sailplane design is becoming more and more complicated and more expensive in the quest for better performance, it was noted that, in future world competitions, sailplanes would be restricted to a simplified 15 metre class. It was hoped that this move would prevent some of the less wealthy countries from being squeezed out of the competition because of financial complications. It was noted that no sailplanes of current championship calibre were available in Canada.

Mr. Ames described the various types of soaring encountered. These include soaring on the vertical component of wind over ridges, the familiar thermal soaring, the use of cumulus cloud base, flying through thunderstorms, which has accounted for many altitude records, and the recent technique of soaring on the standing waves in the lee of high hills.

Mr. Ames then described some of the contest details, covering the briefing of the pilots and a description of the type of tasks assigned to the competitors. These varied from free flights to prescribed triangular course races and flights to designated goals. Many excellent pictures were shown of the actual competitions depicting the difficulties experienced by the pilots in contending with severe thunderstorms and terrain as rugged as the French Alps.

In summing up the speaker noted that, if Canada is to make a better showing in future competitions, it should have more advanced equipment and particularly must train its pilots to fly more difficult tasks and in worse weather than is now the case.

In the question period that followed, it was revealed that, to count as a competition, at least two pilots must complete the run. Each pilot is allowed up to three attempts to make good on the appointed day. Mr. Ames also pointed out that sailplanes are being developed on this continent which are better than the European best but, here as everywhere else, cost is the big deterrent to development.

The speaker was thanked by Mr. Frank Cordon, who expressed gratitude for a new appreciation of the value of the sport as shown by the excellence of performance achieved primarily by superior aerodynamic design. He pointed

out that the Toronto Branch should be very proud that one of its members had committed himself so well in such a demanding competition.

Edmonton—Reported by H. E. Davenport

September Meeting

Over 40 members and guests attended a meeting held on the 18th September in the Officers' Mess, R.C.A.F. Edmonton (Reserve).

Mr. T. Clark, Supervisor of Industrial and Commercial Sales, Imperial Oil Limited, who had previously been introduced by the Chairman, gave an initial talk and then introduced the guest speaker, Mr. Carl Pitcher, Chief Chemical Engineer of Imperial Oil Limited, Calgary Division. Mr. Pitcher had chosen as his subject "Petroleum Products in Aviation", and with great clarity, first discussed the elementary form of fuel structure and its basic chemistry. Aviation gasoline was then analyzed as regards chemical requirements and the various methods of testing these fuels were then discussed. It was pointed out that cracked fuels were not acceptable for use in aviation grade gasoline due to the resultant high gum deposits which subsequently formed. It was shown that impurities for aviation gasoline must be kept to extremely small amounts and the various tests used to determine acceptable purity were discussed at length. The effect of various additives, principally tetra-ethyl lead, was shown and problems related to storage of these fuels were discussed at length. Jet fuels were studied next and it was shown that very serious problems exist, particularly as regards the explosive nature of jet fuel vapour. It was pointed out that even under conditions where normal grounding techniques were used, combustion due to electro-static discharge had occurred. This problem was currently receiving investigation.

After the talk, a general discussion occurred which dealt principally with jet fuels and their characteristics, in which both Mr. Clark and Mr. Pitcher engaged.

Ottawa—Reported by S/L W. M. McLeish

September Meeting

The aeroplane and its myriad forms of gadgetry is normally a sufficient reason for the members to meet once per month to learn more of the aeroplane's encroachment into the lives of its creators. However, thanks to the steadying hand of the better-half, the aeroplane does not entirely engulf us. Proof of this was the opening event of the Ottawa Branch 1956-57 season — a precedent was set and the ladies were invited. To help the members, their wives and guests to relax in amiable surroundings, the evening was arranged at the R.C.A.F. Headquarters Officers' Mess on Gloucester St.

We happened to arrange for the presentation of films concerning matters aeronautical. For the members it was an opportunity to recall the role of the aeroplane in advancing the frontiers of Canada in viewing a T.C.A. film entitled "No Barriers". The film was good and it was nostalgic to see the forerunner of the Norseman, the Bellanca and a Fairchild 82 — the workhorses of the north country during the 30's. "Destination U.K.", a second T.C.A. film, was in the nature of a travelogue with the viewer being introduced to many points of interest in the U.K., including a fashion display for the ladies. Finally we saw a C.P.A.L. film featuring Hawaii.

In all over a hundred attended the first mixed gathering to be held by the Ottawa Branch and its success will no doubt call for a repeat. The ladies all appeared to welcome the opportunity to invade our domain and we can feel sure that the members will be better able to attend future meetings with m'lady's blessings.

MEMBERS

NEWS

S/L W. R. Cole, M.C.A.I., has been posted to the Imperial College of Science, London, England.

H. J. Louch, M.C.A.I., has left Bristol Aircraft (Western) Ltd. in order to take up an engineering appointment with Lockheed Aircraft Corporation, Burbank, Calif., as a Design Engineer.

W. D. H. Roberts, M.C.A.I., has been posted to the R.C.A.F. Station at Cold Lake, as Orenda Technical Representative.

B. Towler, M.C.A.I., who was reported in the September issue as having taken a post with the Boeing Airplane Company, has decided to remain in Canada and is now with Canadian Pacific Air Lines, Ltd., in Vancouver, as a Project Engineer.

S/L W. J. Szostak, Technical Member, has been transferred to No. 3 Fighter Wing, Zweibrucken, Germany.

MEMBERSHIP OF THE C.A.I.

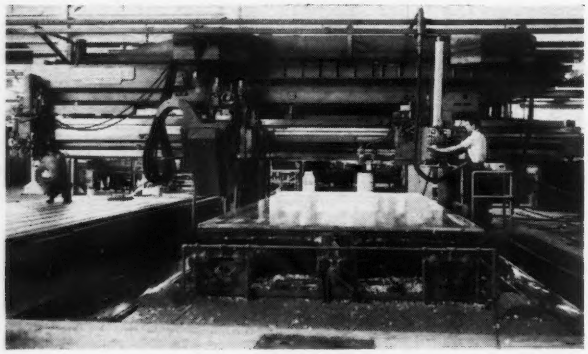
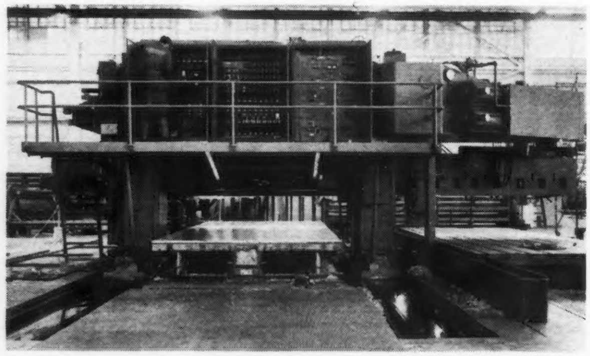
as at the Meeting of the Executive Committee of the Council on the 1st October, 1956.

Technical	**1,635**
Associate	**68**
Total	**1,703**

The Technical grades comprise the following:

Honorary Fellows	11
Fellows	24
Associate Fellows	193
Members	827
Technical Members	453
Technicians	32
Students	95

SUSTAINING MEMBERS

The Kearney & Trecker Skin Mill recently set up at Avro Aircraft Ltd., Malton.

NEWS

Avro Aircraft Ltd. has now put into operation the Kearney & Trecker skin milling machine mentioned by Mr. Young in his paper *Machining Approach to Aircraft Production*, which was published in the last issue of the Journal. Two photographs of the installed machine are shown here.

The work is held in position by vacuum on the work table and the tool operates under the guidance of a stylus, which is in contact with a template placed on the other table. The stylus bears against the template with a load of 8 ounces and its readings are transmitted electronically to the control mechanism of the tool. The tool can be tilted (±2°) and swivelled (±5°) to facilitate cutting tapered skins and converging ribs.

Basic speed of the gantry is 30 inches per minute. On straight through cuts, with rise and fall tracer control, up to 100 inches per minute is possible and for conventional milling cuts, longitudinal feeds and cross feeds, speeds up to 160 inches per minute are possible. Rapid traverse or positioning can be carried out at 240 inches per minute.

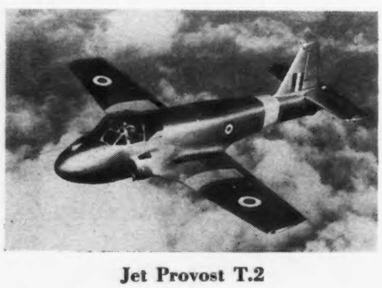
There is provision for automatic indexing of both the cutting head to the next cut and the stylus to the next template.

Canadian Flight Equipment Limited announce that they have changed their name to Campbellford Precision Products Limited.

D. Napier & Son Limited announce that they have now moved to their new offices and are located at 6035 Cote de Liesse Rd. (Marconi Bldg.), Montreal, P.Q.

Field Aviation Company, Ltd., a company associated with Hunting Percival Aircraft Ltd., is demonstrating the Hunting Percival Jet Provost T.2 in Canada. This aircraft is a development from the Jet Provost T.1, which in turn was developed from the piston-engined Provost T.1.

As a result of very satisfactory experience with the Jet Provost T.1 over a year's operation with the R.A.F., Hunting Percival introduced the improved Mark 2 a year ago. The new aircraft has an Armstrong Siddeley Viper ASV.8 engine of 1,750 lb thrust, in place of the ASV.5 of 1,640 lb thrust formerly used. (The Viper was originally designed as a short-life engine for pilotless aircraft but it has since been developed for piloted aircraft and it is expected that its life between major overhauls will soon attain 500 hours.)



Jet Provost T.2

Among other modifications incorporated in the latest aircraft as a result of evaluation experience is the substitution of an extremely simple and reliable hydraulic power system (for the retractable undercarriage, air brakes and wheel brakes) in place of the pneumatic system. Intensive test flying has proved the new hydraulic system to be completely reliable and to require far less maintenance. In addition to the greater simplicity of its operating mechanism, the reduced height of the new undercarriage will also reduce maintenance costs, because the greater ease of access to the cockpit will reduce turn-around times. Other modifications leading to easier and, therefore, cheaper maintenance are the adoption of a simpler pressurized fuel system and the introduction of a single central flight instrument panel in place of the two individual panels formerly fitted.

The Jet Provost T.2 is intended as an ab initio/basic trainer taking pupils through the two stages formerly covered by the piston-engined Provost and the Vampire Trainer. The results of R.A.F. experience, using the Jet Provost T.1, in this simplified training technique have been very encouraging.

SUSTAINING MEMBERS

Of The

CANADIAN AERONAUTICAL INSTITUTE

1956-1957

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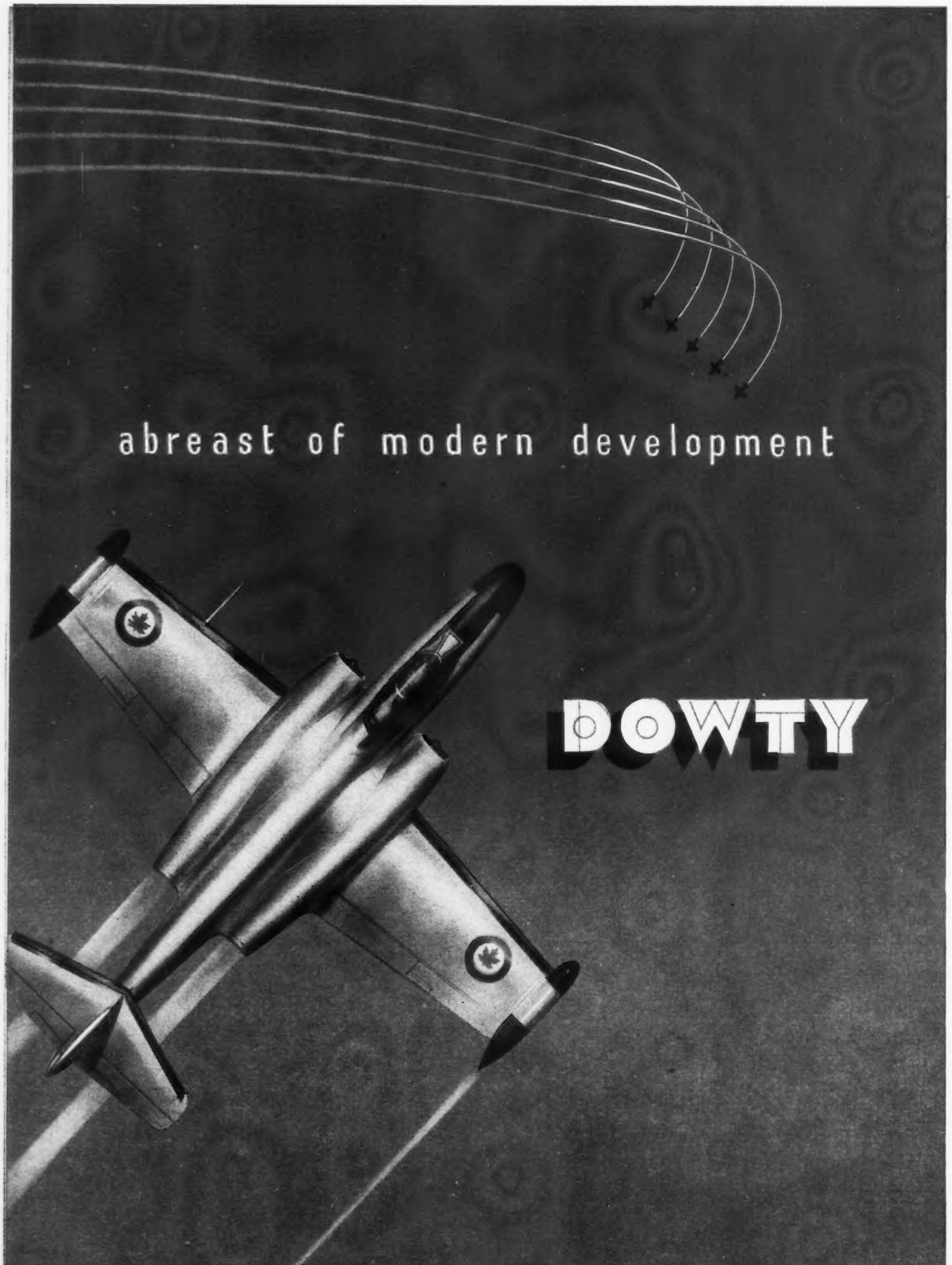
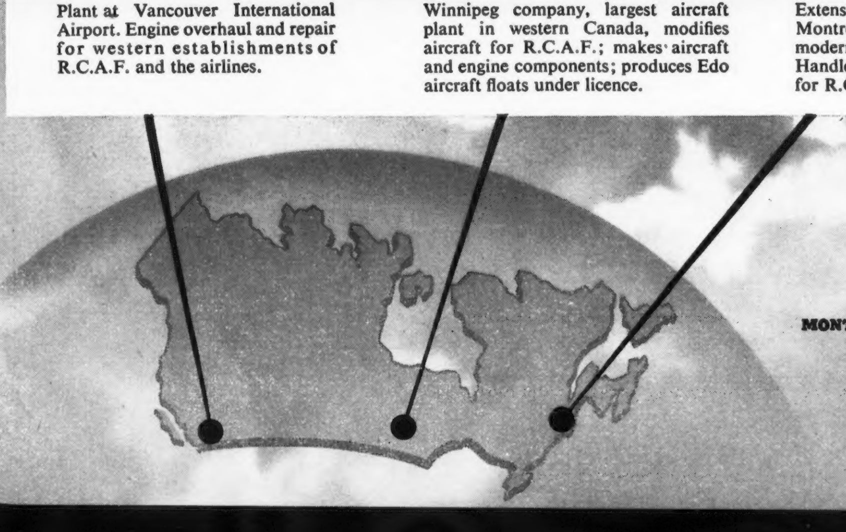

abreast of modern development
DOWTY

this is BRISTOL in Canada...

BRISTOL AERO ENGINES (WESTERN) LIMITED	BRISTOL AIRCRAFT (WESTERN) LIMITED	BRISTOL AERO ENGINES LIMITED
Plant at Vancouver International Airport. Engine overhaul and repair for western establishments of R.C.A.F. and the airlines.	Winnipeg company, largest aircraft plant in western Canada, modifies aircraft for R.C.A.F.; makes aircraft and engine components; produces Edo aircraft floats under licence.	Extensive repair and overhaul plant in Montreal North, with test cells as modern as any in North America. Handles piston-type engines, mainly for R.C.A.F. and T.C.A.



THE BRISTOL AEROPLANE COMPANY OF CANADA (1956) LIMITED

MONTREAL • WINNIPEG • VANCOUVER • MEXICO CITY

Head Office and holding company for associated Canadian companies in the International Aviation Building, Montreal.

collision attack*
This dramatic photograph with its perfectly etched pattern against the blue sky of mid-summer illustrates the split-second successful interception of an RCAF defender CF-100 against an enemy raider. RCAF squadrons across Canada, equipped with AVRO CF-100's, carry out these precise exercises as part of their daily task of round-the-clock alert.
AVRO AIRCRAFT
AVRO AIRCRAFT LIMITED
MALTON, CANADA
MEMBER: A. V. ROE CANADA LIMITED & THE HAWKER SIDDELEY GROUP
*
AIRCRAFT — CF-100's
HEIGHT — 35,000 feet
DEFENDER — Flying from upper right to lower left
RAIDER — In actual combat the raider would have been destroyed at X, the point of interception
The ragged trail background is from a previous interception